FINAL REPORT

Development of Shenandoah River PCB TMDL

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Executive Summary

Several segments of the Shenandoah River are identified on Virginia's 1998 303(d) TMDL Priority List and Report as impaired due to fish consumption advisories issued by the Virginia Department of Health. The Shenandoah River is listed on West Virginia's 1998 Section 303(d) TMDL Priority List and Report due to fish consumption advisories as well. Section 303(d) of the Clean Water Act requires states to develop Total Maximum Daily Loads (TMDL) for waters not meeting water quality standards. The objective of the Shenandoah River PCB TMDL is to achieve water quality standards for polychlorinated biphenyls (PCBs) in the waterbody. The TMDL development process quantitatively assesses the impairment factors so that states can establish water quality-based controls to reduce pollution from both point and nonpoint sources, and to restore and protect the quality of their water resources.

Virginia water quality criteria for PCBs is based on individual Aroclors concentrations although the in-stream field data are measured as total PCBs. A total PCBs criteria was calculated to allow a basis of comparison to the in-stream total PCBs concentration. The calculated Virginia total PCBs water quality criteria of 0.55 ng/L was estimated based on a weight percent of each homolog group of the manufactured Aroclors 1221, 1232, 1016, 1242, 1248,1254, 1260 (GE, 1999). Appendix G contains detailed information about the calculations. Total PCBs concentration and Aroclor concentration follow a proportional relationship of 0.55 ng/L of total PCBs for each 0.44 ng/L Aroclor. The following total PCB water column concentrations must be met: 0.044 ng/L in the West Virginia portions of the Shenandoah River and 0.55 ng/L in the Virginia portions of the river.

The existing PCB data for the Shenandoah River document conditions at or near Avtex Fibers, Inc. Most of the data, based on Aroclor analyses, indicate a failure to detect PCBs in either sediment or surface water. Additional sampling data were therefore warranted to gain a better understanding of the pollutant loading to the stream. A sampling event was conducted from April 26 through April 29, 2001, to support a more in-depth assessment of the spatial variation of PCBs in the Shenandoah watershed and to identify additional potential PCB sources.

The sampling event resulted in two water column samples with total PCBs values above the typical detection limit of 1 ng/L for EPA analytical Method 1681. Effluent from the Avtex wastewater treatment plant (WWTP) and contributions from the Warren County Landfill showed values of 28.2 ng/L and 1.49 ng/L, respectively. Most of the reported lab values were very close to the lab blank, indicating that these values might be minimal (and outside the detection range). Based on these results, the two major potential sources of PCB contamination have been identified as Avtex Fibers, Inc., and the Warren County Landfill.

Based on the data availability for the river, a one-dimensional, steady-state, plug-flow system was developed to represent the linkage between PCB sources in the Shenandoah watershed and the in-stream response. The Shenandoah River was segmented into a series of plug-flow reactors (defined along the entire length of the impaired segment) to simulate a steady-state distribution of PCBs. This approach was necessary to accurately account for the water balance between each segment and the impact of point sources and tributaries to the main stem of the Shenandoah River. Each of the plug-flow reactors defined a mass balance for PCBs for the sediment-water system. PCBs in the water column and sediment layers were computed as concentration profiles with respect to distance.

Using the model, components of the TMDL equation were determined for a loading scenario resulting in Virginia's and West Virginia's water quality criteria being met.

Table 5-2: PCBs TMDL Summary[1]

303(d) ID	Impaired Segment	TMDL (g/yr)	WLA (g/yr)	LA (g/yr)	MOS (g/yr)
VAV-B41R VAV-B55R VAV-B57R VAV-B58R	Main Stem and South Fork Shenandoah River	208.23	179.38*	8.04**	20.82
VAA-B51R	North Fork Shenandoah River	0.833	N/A	0.75	0.083
WV-S_1998	Main Stem Shenandoah River	214.7	179.38*	13.85**	21.47

* Avtex Fibers, Inc. was assigned a WLA of 179.38 g/yr

** Includes allocation to the Warren County Landfill (2.19×10^{-4} g/yr)

[1] Based on 7Q10 flow condition

Contents

Executive Summary i
Contents iii
Figures v
Tables vi

Section 1: Background Information
1.1. Problem Statement 1-1
1.2. Polychlorinated Biphenyls 1-3
1.3. Description of Physical Setting 1-3
1.4. Discussion of 303(d) Listings 1-5
1.5. Applicable Water Quality Criteria 1-9
1.5.1. Designated Uses 1-10
1.5.2. Virginia Water Quality Standards 1-10
1.5.3. West Virginia Water Quality Standards 1-11
1.5.4. Interpreting State Water Quality Standards and FDA Criteria 1-11

Section 2: Data Assessment
2.1. Stream Flow Data 2-1
2.2. Water Quality Data 2-4
2.2.1. Water Column Data 2-5
2.2.2. Fish Tissue Data 2-9
2.2.3. Sediment Data 2-10
2.2.4. Clam Tissue Data 2-10

Section 3: Source Assessment
3.1. Nonpoint Source Analysis 3-1
3.1.1. Washoff from Land Surfaces 3-1
3.1.2. Streambed Sediments 3-2
3.2. Point Source Analysis 3-4
3.2.1. Avtex Fibers, Inc 3-4
3.2.1.1. Site Description 3-4
3.2.1.2. Corporate History 3-4
3.2.1.3. History of PCBs Contamination 3-5
3.2.1.4. Site Remediation 3-6
3.2.2. Toxic Substance Control Act 3-9
3.2.3. Resource Conservation and Recovery Act 3-9
3.2.4. Comprehensive Environmental Response, Compensation, and Liability Act 3-10
3.2.5. EPA Permit Compliance Systems and Industrial Facility Discharges 3-11

Section 4: Supplemental PCB Sampling in Shenandoah River
4.1. Sampling Event 4-2
4.2. Preliminary Unvalidated Total PCBs Results 4-4

Section 5: Technical Approach
5.1. Source Response Linkage 5-1
5.1.1. Model Development 5-1
5.1.2. Source Representation 5-3
5.1.3. Analytical Assumption 5-3
5.2. TMDL Calculations 5-4
5.2.1. Wasteload Allocations 5-6
5.2.2. Load Allocation 5-6
5.2.3. Margin of Safety 5-6
5.3. Seasonal Variations 5-6
5.4. Fish Advisory Criteria and TMDL Endpoint 5-7

Section 6: Reasonable Assurances 6-1
Section 7: Public Participation . . . .
. . 6-2

References R-1

Appendices

Appendix A-1: USGS Gauge Flow Data A-1
Appendix A-2: Water Quality Data A-3
Appendix B-1: RCRA Sites Information B-1
Appendix B-2: CERCLA Sites Information B-3
Appendix C: PCS-Industrial Facilities C-1
Appendix D: Quality Assurance Program Plan D-1
Appendix E: Shenandoah Sampling Event Photographs E-1
Appendix F: Plug Flow Reactor Model F-1

Figures

Figure 1-1: Location of Shenandoah River Watershed . . . 1-2
Figure 1-2: Land Use Distribution in the Shenandoah River Watershed . . . 1-4
Figure 1-3: Fish Tissue FDA Exceedances . . . 1-9
Figure 2-1:Water Quality Monitoring and Flow Gauge Stations . . . 2-2
Figure 2-2: Sediment Sampling Locations from Multiple Agencies . . . 2-6
Figure 2-3: Detected PCBs in Water Column Samples . . . 2-7
Figure 2-4: Clam and Fish Sampling Locations from Multiple Agencies . . . 2-8
Figure 2-5: Total PCBs Concentrations in Fish Tissue . . . 2-9
Figure 2-6: Total PCBs Concentrations in Sediments . . . 2-10
Figure 3-1: Water Sediment Interaction . . . 3-3
Figure 3-2: PCS and IFD Facilities in the Shenandoah River Basin . . . 3-13
Figure 4-1: Sampling Site Location Map . . . 4-2
Figure 5-1: Plug-Flow Reactor Representation of the Shenandoah River . . . 5-2
Figure 5-2: Processes and Interaction Represented in the Plug-Flow Reactor Model . . . 5-2
Figure 5-3: Total Modeled PCBs in Water Column Along the Length of the Shenandoah River . . . 5-5

Tables

Table 1-1: 303(d) Impaired Segment Listings 1-1
Table 1-2: Land Use Distribution 1-3
Table 1-3: Percent Land Use Distribution by Subbasin and Land Type 1-5
Table 1-4: Analysis of FDA Exceedances in the Shenandoah River 1-7
Table 1-5: Virginia State Water Control Board Water Quality Data, Fish-Type 1-8
Table 1-6: Applicable Virginia Water Quality Criteria 1-10
Table 1-7: Applicable West Virginia Water Quality Criteria 1-11
Table 1-8: Mass Conversion Table 1-12
Table 1-9: Water Quality Criteria for Total PCBs 1-12
Table 2-1: Inventory of Data and Information for the Shenandoah River Watershed 2-1
Table 2-2: Statistical Summary of Key USGS Stations in the Shenandoah River Watershed 2-3
Table 2-3: Seasonal Flow Analysis at USGS 1631000 2-4
Table 2-4: In-stream Water Quality Overview 2-5
Table 2-5: Detectable Water Column Data 2-5
Table 2-6: Superfund Data, Clams-Type 2-10
Table 3-1: RCRA Facilities 3-10
Table 3-2: CERCLA Sites 3-11
Table 4-1: Summary of Samples Collected During Sampling Event April 26-29, 2001 4-3
Table 4-2: Total PCBs Concentration Data (UNVALIDATED) 4-4
Table 5-1: Total PCBs Discharge Characteristics in the Shenandoah River 5-3
Table 5-2: PCB TMDL Summary 5-5
Table 5-3: Total PCBs Water Quality Criteria 5-7
Table 5-4: Total PCBs in Fish Tissue vs. Sediment 5-8

Section 1: Background Information

1.1. Problem Statement

The Shenandoah River drains 1,957,690 acres of land which is predominantly forest. The headwaters of the River are in the Appalachian and Shenandoah Mountains and drain north-northeast before merging near Front Royal, Virginia and flowing into the Potomac River in West Virginia. The maximum elevation in the basin is approximately 3,350 feet in the Appalachian Mountains; the minimum elevation, 300 feet, occurs at the confluence with the Potomac River. The Shenandoah River basin encompasses three subbasins or 8-digit U.S. Geological Survey (USGS) Hydrologic Unit Codes (Figure 1-1):

- HUC 02070005 South Fork of the Shenandoah River (S.F. Shenandoah River)
- HUC 02070006 North Fork of the Shenandoah River (N.F. Shenandoah River)
- HUC 02070007 Shenandoah River

Several segments of the Shenandoah River are identified on Virginia's 1998 Section 303(d) TMDL Priority List and Report as impaired due to fish consumption advisories issued by the Virginia Department of Health. The Shenandoah River is listed on West Virginia's 1998 Section 303(d) TMDL Priority List and Report due to fish consumption advisories as well. The first listed stream segment is located between the towns of Front Royal and Berryville, Virginia. The segment is 36.45 miles in length, beginning at the Rt. 619 bridge over the S.F. Shenandoah River in Front Royal and ending at the Virginia/West Virginia state line. The second segment is 5.33 miles in length, beginning at the Passage Creek confluence with the N.F. Shenandoah River and ending at the N.F. Shenandoah River's confluence with the S.F. Shenandoah River in Front Royal. The third segment is 19.45 miles long and runs from the West Virginia line to the Shenandoah River's confluence with the Potomac River. Table 1-1 lists the impaired segments in the Shenandoah River basin. The impaired segments encompass Jefferson, Clarke and Warren counties. Figure 1-1 shows the location of the listed segments.

Section 303(d) of the Clean Water Act requires states to develop Total Maximum Daily Loads (TMDLs) for waters that do not meet water quality standards. The objective of the Shenandoah PCB TMDL is to achieve water quality standards for polychlorinated biphenyls (PCBs) in the waterbody. The TMDL development process quantitatively assesses the impairment factors so that states can establish water quality-based controls to reduce pollution from both point and nonpoint sources and to restore and protect the quality of their water resources.

Table 1-1: 303(d) Impaired Segment Listings

303 ID	Branches	Miles	Description
WV-S-1998	Main Stem	19.45	VA State Line to Potomac River
VAV-B41R VAV-B55R VAV-B57R VAV-B58R	Main Stem and South Fork	36.45	Rte 619 to VA State Line
VAV-B51R	North Fork	5.33	Passage Creek to confluence

Sources: Virginia Department of Environmental Quality and West Virginia Department of Environmental Protection.

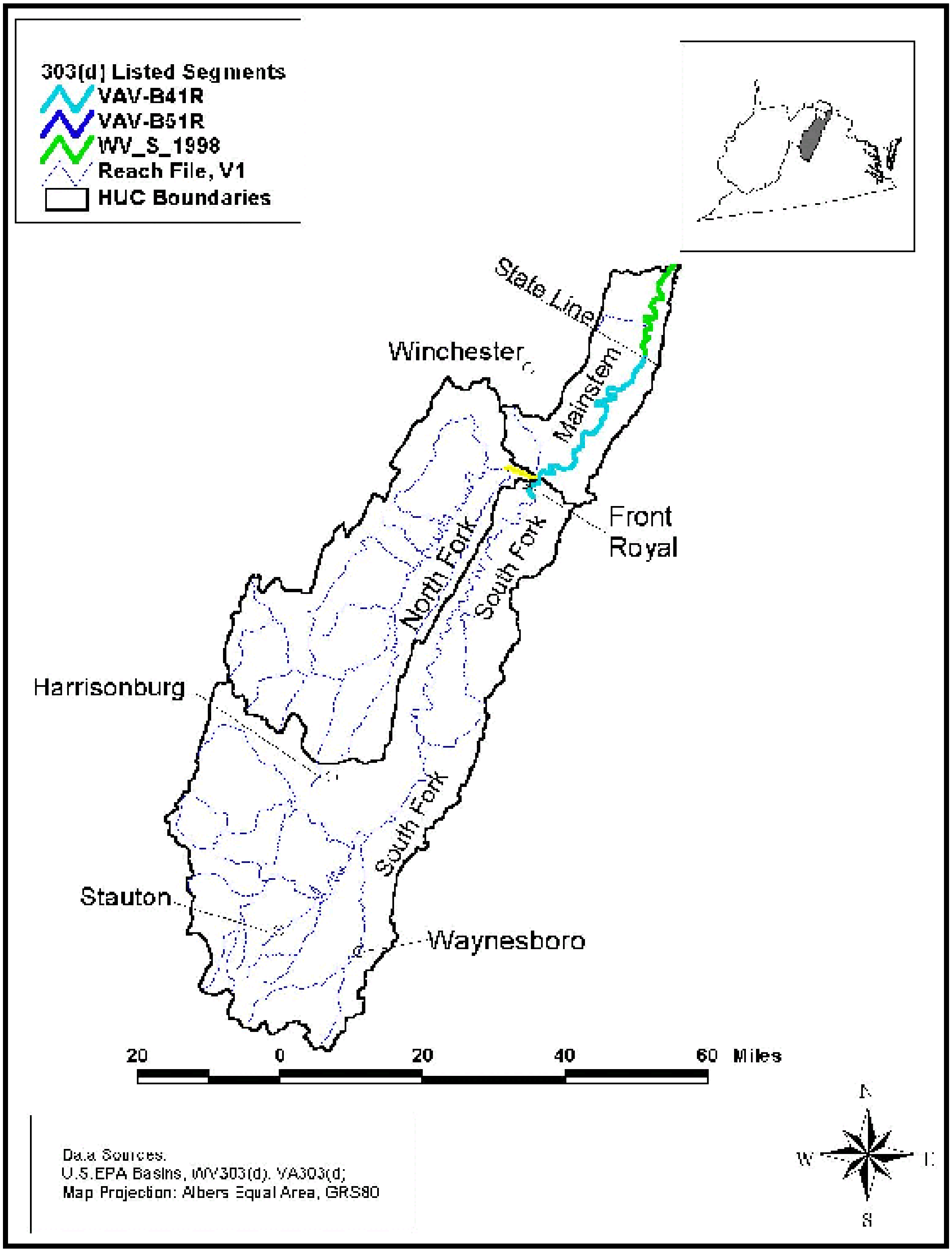

Figure 1-1: Location of Shenandoah River Watershed

1.2. Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs) consist of 209 related chemical compounds that were manufactured and sold as mixtures under various trade names, including Aroclor, Phenoclor, Clophen, and Kenechlor (GE, 1999). They were used from approximately the 1940s through the 1970s. Because they possess excellent dielectric and flame resistant properties, PCBs were extensively used as heat transfer fluids, hydraulic fluids, flame retardants, and dielectric fluids. These same properties cause PCBs to accumulate in the fatty tissue of biota and bioaccumulate in the food chain. Concerns regarding potential human health effects led to cessation of PCB production and use in the United States in the 1970s.

Each of the 209 possible PCB compounds (called congeners) consists of two phenyl groups and chlorine atoms (chlorination). Individual PCB congeners differ in the number and position of the chlorine atoms. PCBs were manufactured and sold in the United States under the Aroclor trade name (GE, 1999) and several Aroclor products were manufactured. The five principal compounds were Aroclor 1221, 1242, 1016, 1254, and 1260. These products differed in their degree of chlorination.

1.3. Description of Physical Setting

The Shenandoah River, the North Fork of the Shenandoah River, the South Fork of the Shenandoah River, and the South Fork of the Shenandoah headwaters are included in the Reach File 1 stream network, which is based on 1:500,000 resolution maps.

A breakdown of the land area by general land use category is included in Table 1-2 for the 2000 time period. Figure 1-2 illustrates the land use distribution within the Shenandoah River watershed.
The entire basin is 51 percent forest and 41percent agriculture with more forest than agriculture in the two upstream sub-basins (Table 1-3). The downstream sub-basin 56 percent agricultural lands. Urban lands are approximately 5 to 8 percent throughout the basin, and are focused near Front Royal, Winchester, and Waynesboro.

Table 1-2: Land Use Distribution

Land Use Name	Main Fork (acres)	North Fork (acres)	South Fork (acres)	Total Area (acres)
Urban or Built-up land	13,945	34,901	89,385	138,232
Agricultural land	130,804	237,716	426,360	794,879
Forest land	73,674	381,082	549,650	1,004,410
Range land	0	0	669	669

Water	3,938	413	3,805	8,156
Barren land	4,049	3,859	3,414	11,322
Unclassified	4	7	9	20
Total	**226,414**	**657,978**	**1,073,290**	**1,957,690**

Note: These land use data are based on a 100-m^2 resolution.

Source: Gap Analysis Program (GAP) land use developed by USGS Biological Resources for assessing regional conservation status of vertebrate species and land cover types.

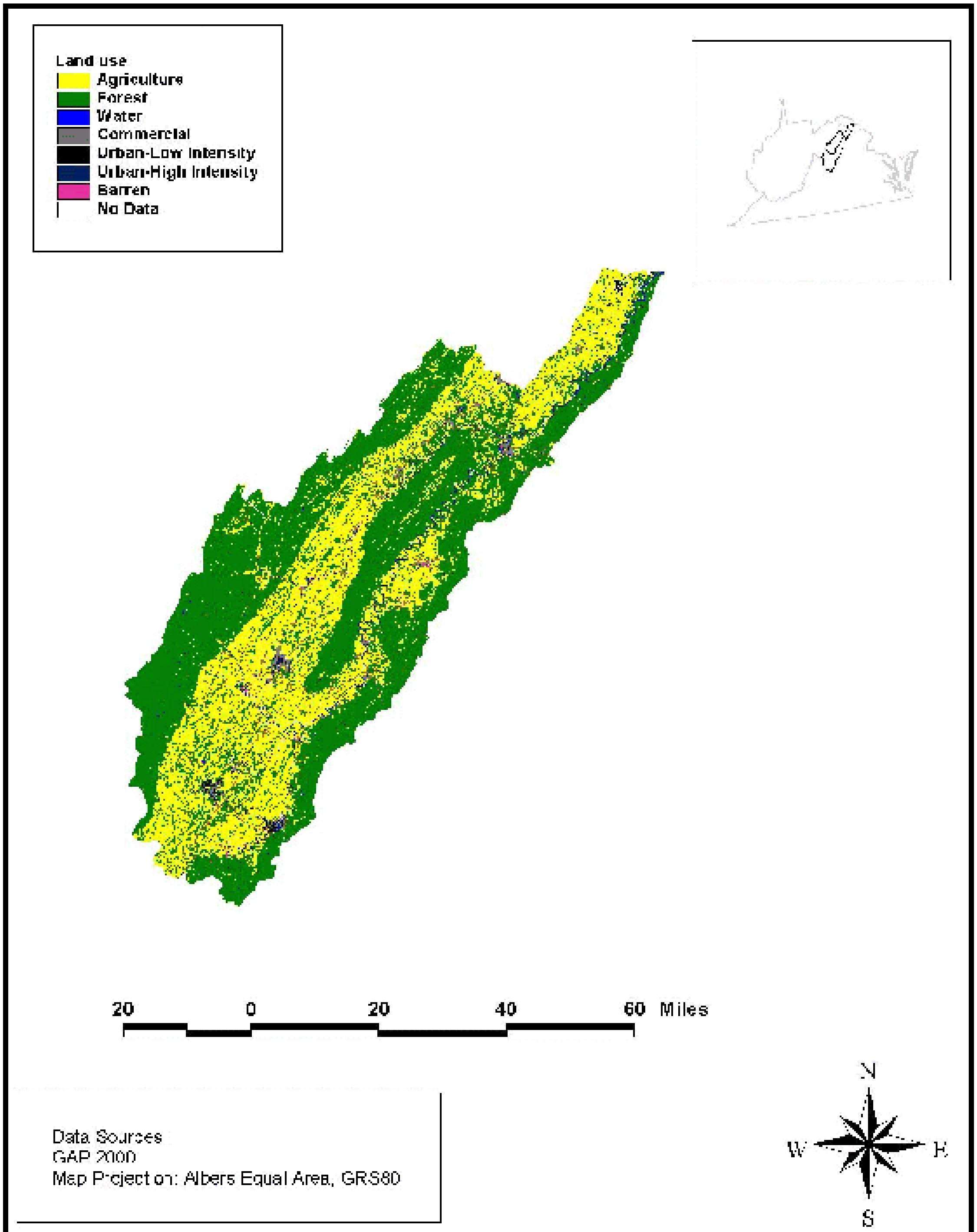

Figure 1-2: Land Use Distribution in the Shenandoah River Watershed

Table 1-3: Percent Land Use Distribution by Subbasins and Land Type

Land Use	Main Fork	North Fork	South Fork	Basin Percentage
Urban or Built-up Land	6.2%	5.3%	8.3%	7.1%
Agricultural Land	57.8%	36.1%	39.7%	40.6%
Forest Land	32.5%	57.9%	51.2%	51.3%
Range Land	0.0%	0.0%	0.1%	0.0%
Water	1.7%	0.1%	0.4%	0.4%
Barren Land	1.8%	0.6%	0.3%	0.6%
Unclassified	0.0%	0.0%	0.0%	0.0%
Total area (acres)	**226,414**	**657,978**	**1,073,290**	**1,957,690**

Source: Gap Analysis Program (GAP) land use developed by USGS Biological Resources for assessing regional conservation status of vertebrate species and land cover types.

1.4. Discussion of 303(d) Listings

The Shenandoah River is included on the Section 303(d) list of both Virginia and West Virginia. The listings are based on fish tissue advisories issued by the health departments of both states. The location of the listed segments is shown in the basin map, Figure 1-1. Tables 1-4 and 1-5 show exceedances of the Federal Food and Drug Administration (FDA) criterion of 2 mg/kg within the Shenandoah River. The Virginia Department of Health (VDH) uses a 0.6 mg/kg concentration of PCBs in fish tissue screening level to issue a fish consumption advisory for PCBs.

On May 17, 1989, the State of Virginia issued a "do not eat" advisory for all species of fish in the Shenandoah River and in segments of the North Fork and South Fork of the Shenandoah. VDH issues an advisory based on observed violations of the screening level. Fish having PCB levels that exceed 2.0 mg/kg should not be consumed (West Virginia Department of Environmental Protection, 2001).

This fish consumption advisory was issued in response to the results of EPA core sampling conducted in 1988. EPA sampled three sites in 1988: (1) the North Fork of the Shenandoah River at Front Royal, (2) the South Fork of the Shenandoah River at Front Royal, and (3) the Shenandoah River 3 miles upstream of the Virginia/West Virginia state line. All PCB samples from site 1 were below the detection limit except one carp which had a PCB concentration of 4.2 mg/kg. In the South Fork of the Shenandoah River (site 2), concentrations ranged from nondetect to 92.0 mg/kg. At the Shenandoah River (site 3), PCB concentrations ranged from 2.0 to 5.2 mg/kg.

In response to Virginia's actions, West Virginia also issued a "do not eat" advisory for all species on September 7, 1989. This advisory was also based on the FDA criterion . Fish samples were collected in October 1989 to validate this decision. The results of the October 1989 sampling did not support an "all species" advisory. On January 24, 1990, the state issued another advisory, placing the "do not eat" advisory on catfish, carp, and suckers only. The “do not eat” advisory has remained in place until the present time.

In September 2000, the West Virginia Fish Consumption Advisory Technical Committee was created by Governor’s Executive Order. One objective of this committee is to apply the newly developed risk-based protocols presented in the “West Virginia Sportfish Consumption Advisory Guide” (Warnick, 2000) to new and existing fish tissue data. Risk-based advisories recommend consumers eat fewer meals of fish containing PCB concentrations that are below the FDA level. Due to impending TMDL development, the committee assigned a higher priority to the re-evaluation of Shenandoah River fish tissue data. Advisory language is currently being developed and a formal advisory update is planned for July 2001. This advisory, which is based on data collected in 1989 and 1993, will reinforce the existing “do not eat” advisory for catfish, carp, and suckers and recommend limiting meals of all other species to one meal per month.

On October 16, 1989, the Virginia Water Control Board identified the source of the PCB contamination in the Shenandoah River as Avtex Fibers, Inc. The Environmental Reporter (vol. 20, no.29, November 17, 1989) announced that Virginia officials had revoked Avtex's water discharge permit, effective November 9, 1989. The state also sued Avtex for extensive permit violations. The company agreed to pay more than $17 million in fines for violation of its water discharge permit. On November 11, 1989, Avtex Fibers shut down the plant following this action. Since 1989 emergency actions, including removal and disposal of PCB contaminated soils, have taken place. The site was placed on EPA’s National Priority List (NPL) in 1986, where it remains today.

Figure 1-3 plots the fish tissue sample data against the FDA fish advisory criterion. Samples were taken within the Shenandoah watershed, and the data show that the high exceedances occurred in the late 1980s.

Table 1-4: Analysis of FDA Exceedances in the Shenandoah River

DATE	Stream	Location	Species	Total PCBs (mg/kg)	Exceeds FDA Criterion (2 mg/kg)
10/11/89	Shenandoah River	Meyerstown	Bluegill	0.29	No
10/11/89	Shenandoah River	Meyerstown	Channel Catfish	5.4	Yes
10/11/89	Shenandoah River	Meyerstown	Golden Redhorse Sucker	11.8	Yes
10/11/89	Shenandoah River	Meyerstown	Pumpkinseed	0.56	No
10/11/89	Shenandoah River	Meyerstown	Redbreast Sunfish	0.78	No
10/11/89	Shenandoah River	Meyerstown	Smallmouth Bass	0.93	No
10/11/89	Shenandoah River	Millville	Bluegill	0.41	No
10/11/89	Shenandoah River	Millville	Channel Catfish	4.3	Yes
10/11/89	Shenandoah River	Millville	Golden Redhorse Sucker	3.8	Yes
10/11/89	Shenandoah River	Millville	Pumpkinseed	0.46	No
10/11/89	Shenandoah River	Millville	Redbreast Sunfish	0.46	No
10/11/89	Shenandoah River	Millville	Smallmouth Bass	0.56	No
10/28/93	Shenandoah River	Millville	Bluegill	0.190	No
10/28/93	Shenandoah River	Millville	Channel Catfish	4.015	Yes
10/28/93	Shenandoah River	Millville	Golden Redhorse Sucker	4.890	Yes
10/28/93	Shenandoah River	Millville	Pumpkinseed	0.114	No
10/28/93	Shenandoah River	Millville	Redbreast Sunfish	0.196	No
10/28/93	Shenandoah River	Millville	Smallmouth Bass	0.344	No
10/28/93	Shenandoah River	Meyerstown	Channel Catfish	11.74	Yes
10/28/93	Shenandoah River	Meyerstown	Golden Redhorse Sucker	5.44	Yes
10/28/93	Shenandoah River	Meyerstown	Redbreast Sunfish	0.238	No
10/28/93	Shenandoah River	Meyerstown	Smallmouth Bass	0.419	No

Source: West Virginia Department of Environmental Protection.

Table 1-5: Virginia State Water Control Board Water Quality Data Fish-Type

Date	Stream/Location	Species	Total PCBs, (mg/kg)	Exceeds VDH Criterion (0.6 mg/kg)
07/24/79	Shenandoah River		ND	
08/04/81	Shenandoah River		0.50	
07/27/83	Shenandoah River		2.30	Yes
08/13/85	Shenandoah River		ND	
07/16/86	Shenandoah River		ND	
08/18/88	Shenandoah River		ND	
07/26/79	Shenandoah River		ND	
07/28/83	Shenandoah River		ND	
08/14/85	Shenandoah River		ND	
08/18/88	Shenandoah River		4.20	Yes
09/12/90	Shenandoah River		ND	
09/12/90	Shenandoah River		ND	
09/13/90	Shenandoah River		ND	
07/16/87	Shenandoah River		5.20	Yes
06/05/90	Shenandoah River		4.40	Yes
07/16/92	Shenandoah River		ND	
06/05/90	Shenandoah River		7.50	Yes
06/06/90	Shenandoah River		9.70	Yes
07/14/92	Shenandoah River		ND	
06/06/90	Shenandoah River		18.00	Yes
08/17/88	Shenandoah River		12.00	Yes
07/26/79	Shenandoah River		ND	
07/28/83	Shenandoah River		ND	
08/14/85	Shenandoah River		ND	
08/16/88	Shenandoah River		21.00	Yes
08/17/88	Shenandoah River		110.00	Yes
06/06/90	Shenandoah River		50.00	Yes
07/14/92	Shenandoah River		ND	
07/16/92	Shenandoah River		ND	
10/08/99	Shenandoah River near RT 7	White Sucker	0.03	
08/17/99	Shenandoah River near RT 7	Channel Catfish	2.07	Yes
10/06/99	Shenandoah River near RT 7	Redbreast Sunfish	0.05	
10/06/99	Shenandoah River near RT 7	Smallmouth Bass	0.12	
10/08/99	Shenandoah River near RT 50	White Sucker	0.06	
08/27/99	Shenanadoh River near RT 50	Channel Catfish	0.56	Yes
10/08/99	Shenandoah River near RT 50	Redbreast Sunfish	0.03	

Date	Stream/Location	Species	Total PCBs, (mg/kg)	Exceeds VDH Criterion (0.6 mg/kg)
10/08/99	Shenanadoh River near RT 50	Smallmouth Bass	0.06	
10/07/99	South Fork Shenandoah near Riverton	Carp	16.66	Yes
09/01/99	South Fork Shenandoah near Riverton	Channel Catfish	0.29	
10/07/99	South Fork Shenandoah near Riverton	Redbreast Sunfish	0.05	
10/07/99	South Fork Shenandoah near Riverton	Smallmouth Bass	0.14	

ND = not detected.
Source: STORET.

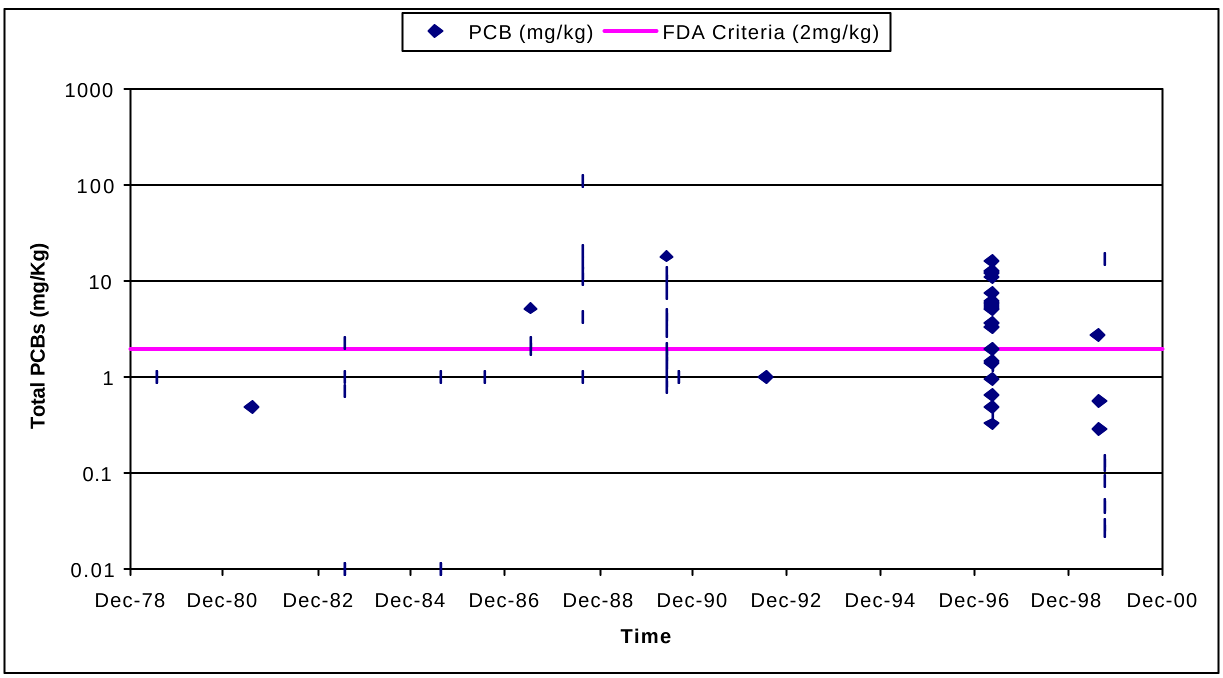

Figure 1-3: Fish Tissue FDA Exceedances (Readings are actual composite tissue samples)

1.5. Applicable Water Quality Criteria

Development of a PCB TMDL for the Shenandoah River requires consideration of water quality criteria for both Virginia and West Virginia, because the impaired segments are in both states. Water quality criteria are based on designated uses and vary from one state to the next. The water quality criteria must be met in both states to meet the TMDL requirements. Based on the existing criteria, reductions in PCB levels above what are necessary to meet the criteria in Virginia are required for the Shenandoah River to comply with the West Virginia criteria.

1.5.1. Designated Uses

Virginia: All waters in Virginia have the designated uses of contact recreation, propagation of fish and game, and production of edible and marketable natural resources such as fish (9 VAC 25-260-10). Additional uses apply to several river sections that are used as a water supply source. The South Fork of the Shenandoah River upstream of the impaired section and the main stem of the Shenandoah River from 5 miles upstream of the Berryville raw water intake to the Virginia/West Virginia state line are designated for water supply.

West Virginia: West Virginia water quality criteria state designated uses of propagation of fish and other aquatic life and contact recreation (46-1-6). Additional uses apply to a portion of the Shenandoah River near Charlestown (which is designated as Class A: Water Supply, Public).

1.5.2. Virginia Water Quality Standards

Virginia's water quality standards for PCBs are defined for individual PCB Aroclors for freshwater and saltwater as numeric constituent concentrations. These numeric criteria are based on risk assessment methods. Table 1-6 presents the Virginia water quality criteria for PCBs based on the designated uses. Because the Shenandoah River has multiple designated uses, the drinking water criteria were selected as the most stringent criteria.

Table 1-6: Applicable Virginia Water Quality Criteria

POLLUTANT	USE DESIGNATION					
	Aquatic Life				Human Health	
	Freshwater		Saltwater			
	Acute [a] (µg/L)	Chronic [b] (µg/L)	Acute [a] (µg/L)	Chronic [b] (µg/L)	Public Water Supplies [c] (µg/L)	All Other Surface Waters [d] (µg/L)
PCB-1242[e]	-	0.014	-	0.030	0.00044	0.00045
PCB-1254[e]	-	0.014	-	0.030	0.00044	0.00045
PCB-1221[e]	-	0.014	-	0.030	0.00044	0.00045
PCB-1232[e]	-	0.014	-	0.030	0.00044	0.00045
PCB-1248[e]	-	0.014	-	0.030	0.00044	0.00045

PCB-1260[e]	-	0.014	-	0.030	0.00044	0.00045
PCB-1016[e]	-	0.014	-	0.030	0.00044	0.00045

[a] One hour average concentration not to be exceeded more than once every 3 years on the average.
[b] Four-day average concentration not to be exceeded more than once every 3 years on the average.
[c] Not to exceed.
[d] Unless otherwise noted, these criteria have been calculated to protect human health from toxic effects through fish consumption.
[e] Known as suspected carcinogen. Human health standards are for a risk level of 10^{-5}.
Source: Virginia State Water Control Board, 1997.

1.5.3. West Virginia Water Quality Standards

West Virginia's Requirements Governing Water Quality Standards (West Virginia SOS, 2000) defines water quality criteria for surface waters as a numeric constituent concentration or a narrative statement representing a quality of water that supports a designated use or uses of the waterbody. Total PCBs are given numeric criteria under the aquatic life and the human health designation categories based on risk assessment methods (Table 1-7).

Table 1-7: Applicable West Virginia Water Quality Criteria

POLLUTANT	USE DESIGNATION						
	Aquatic Life				Human Health		All Other Uses
	B1, B4		B2		C[c]	A[d]	
	Acute[a]	Chronic[b]	Acute[a]	Chronic[b]			
PCB[e], Total (ng/L)	-	14.0	-	14.0	0.045	0.044	0.045

[a] One hour average concentration not to be exceeded more than once every 3 years on the average.
[b] Four-day average concentration not to be exceeded more than once every 3 years on the average.
[c] Unless otherwise noted, these criteria have been calculated to protect human health from toxic effects through fish consumption.
[d] Unless otherwise noted, these criteria have been calculated to protect human health from toxic effects through drinking water and fish consumption.
[e] Known or suspected carcinogen. Human health standards are for a risk level of 10^{-6}.
Source: West Virginia SOS, 2000; B1 = warm water fishery streams, B4 = wetlands, B2 = trout waters, A = water supply, public

1.5.4. Interpreting State Water Quality Standards and FDA Criteria

There are both fish tissue and water column criteria for PCBs. FDA advisory criteria are based solely on fish tissue concentrations whereas state criteria are based on water column and fish tissue concentrations. No sediment criteria have been identified.

Both Virginia's and West Virginia's water column standards are based on risk assessment methods. Virginia's standard uses a $1:10^5$ risk versus the $1:10^6$ risk used by West Virginia. The West Virginia standard for Total PCBs is 0.044 ng/L, and the Virginia water column criterion for each PCB Arochlor is 0.44 ng/L.

Table 1-8: Mass Conversion Table

Unit	Gram (g)	Milligram (mg)	Microgram (µg)	Nanogram (ng)	Picogram (pg)
Gram (g)	1	1.00E+03	1.00E+06	1.00E+09	1.00E+12
Milligram (mg)	1.00E-03	1	1.00E+03	1.00E+06	1.00E+09
Microgram (µg)	1.00E-06	1.00E-03	1	1.00E+03	1.00E+06
Nanogram (ng)	1.00E-09	1.00E-06	1.00E-03	1	1.00E+03
Picogram (pg)	1.00E-12	1.00E-09	1.00E-06	1.00E-03	1

Because the Section 303(d) listing is based on fish advisory criterion, the fish tissue criterion has been converted to a corresponding water column concentration for comparison to the water quality standards presented in Sections 1.4.2 and 1.4.3. The fish tissue endpoint is based on health advisories for consumption. The FDA advisory level is 2 mg/kg while, the Virginia Department of Health (VDH) uses a 0.6 mg/kg advisory level. West Virginia is currently developing a formal advisory update which is planned for July 2001. The fish tissue levels can be compared to the water column standards using an EPA bioconcentration factor (BCF).

The transfer of PCBs through the food web can be described as a bioconcentration factor or BCF. The BCF is a ratio of the contaminant concentration in the species of interest to the concentration in the exposure source. In this case, it describes the accumulation of PCBs from the water column. The BCF is often used as a screening level description of bioaccumulation for all aquatic biota. The BCF for PCBs is 31,200 L/kg (EPA 440/5-80-068) and represents the accumulation rate of PCBs in fish tissues.
The conversion equation is:

$$\text{Tissue level} = \text{water concentration} * \text{BCF} * \text{unit conversions} \qquad (1\text{-}1)$$

Table 1-9 summarizes the advisory criteria and water quality criteria and provides a direct comparison between tissue and water column levels. To meet the water quality criteria in all the impaired sections of the Shenandoah River, the water column concentration of 0.044 ng/L must be met in West Virginia. This concentration has therefore been identified as the TMDL endpoint.

Table 1-9: Water Quality Criteria for Total PCBs

Media	Agency	Tissue Level (mg/Kg)	Tissue Level (µg/Kg)	Water Level (ng/L)
Fish	FDA[c]	**2.0[a]**	2000	64.1
Fish	VDH	**0.6**	600	19.2
Water	VA	0.014	14	**0.440[ab]**
Water	WV	0.0014	1.4	**0.044[a]**

[a] Water quality standards. All others are calculations.

[b] Aroclors 1242, 1254, 1221, 1232, 1248, 1260, 1016.

[c] No advisory level is available for West Virginia; therefore, the state applies the FDA criterion of 2 mg/kg. West Virginia is currently developing a formal advisory update which is planned for July 2001.

Sources: Virginia Department of Environmental Quality and West Virginia Department of Environmental Protection.

Section 2: Data Assessment

This section identifies and examines available data to characterize the Shenandoah River and its watershed. A wide range of data and information was used in the development of the Shenandoah PCB TMDL. The categories of data used include physiographic data that describe the physical conditions of the watershed, environmental monitoring data that identify potential pollutant sources and their contribution, and in-stream water quality monitoring data.

Table 2-1: Inventory of Data and Information for the Shenandoah River Watershed

Data Category	Description	Data Source(s)
Watershed Physiographic Data	Land Use (MRLC[a], GAP[b])	WVDEP, VADEQ
	Stream Reach Coverage (RF1, RF3)	U.S. EPA BASINS
	Weather Information	National Climatic Data Center
Environmental Monitoring Data	NPDES Data	WVDEP, VADEQ
	Discharge Monitoring Report Data	WVDEP, VADEQ
	303(d) Listed Waters	WVDEP, VADEQ
	Water Quality Monitoring Data	EPA STORET, Superfund, VASWCB, USGS, WVDEP

[a] Multi-resolution Land Characteristics (MRLC) land use developed by consortium of EPA, USGS, Dept of Interior and NOAA
[b] Gap Analysis Program (GAP) land use developed by USGS Biological Resources for assessing regional conservation status of vertebrate species and land cover types.

2.1. Stream Flow Data

A search of the USGS Web Site for historical daily flows for the Shenandoah River found 34 stations with flows. Long-term daily flows for the Shenandoah River are available from October 1930 through September 1999 at several gauging stations including USGS01631000 (Table 2-2), which is located upstream of the impaired segments. An additional 23 stations with peak flow data were found. Appendix A-1 contains a list of all the USGS stations in the watershed. Figure 2-1 shows the gauging stations.

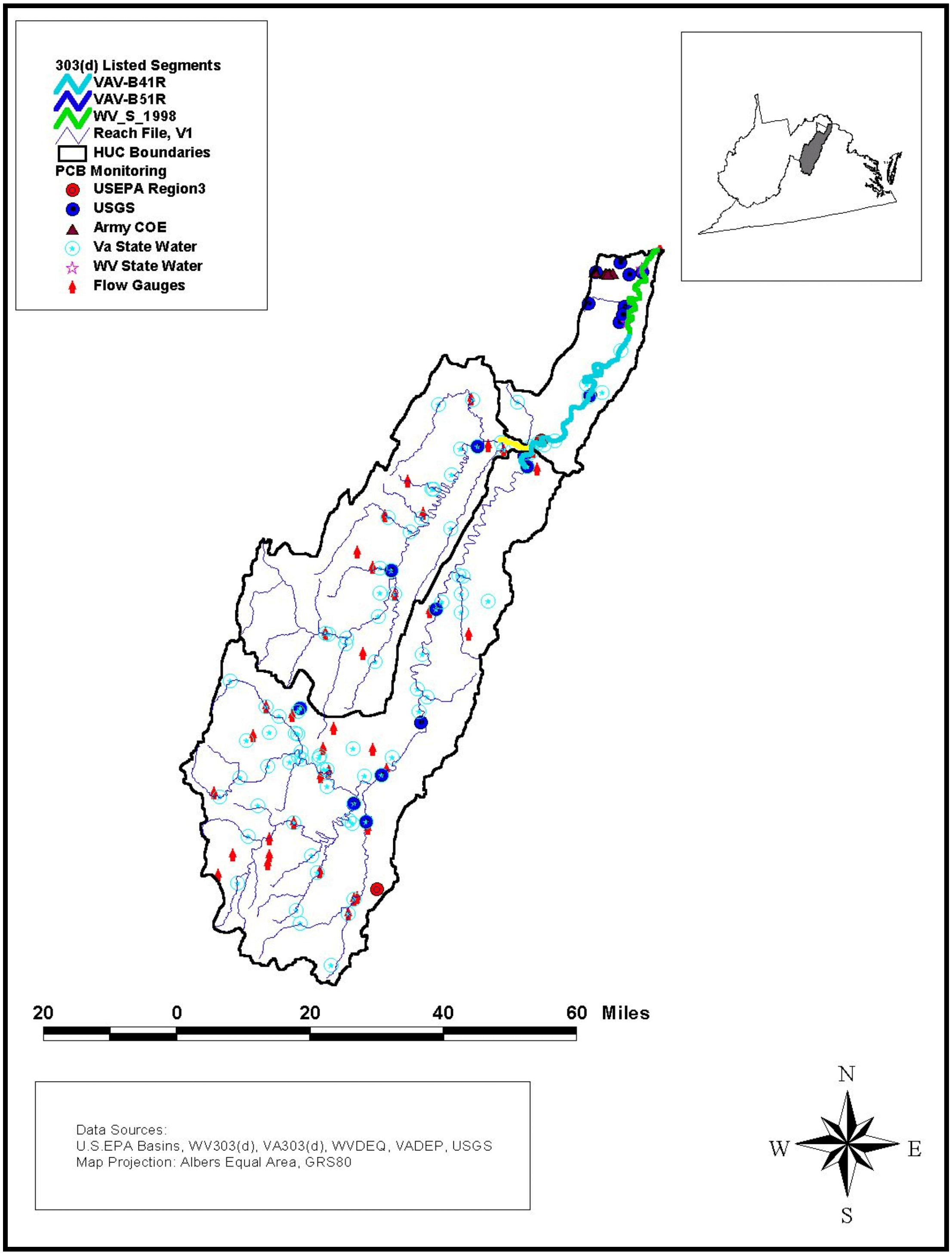

Figure 2-1: Water Quality Monitoring and Flow Gauge Stations

Table 2-2: Statistical Summary of Key USGS Stations in the Shenandoah River Watershed

USGS Station	Location	Drainage Area (mi^2)	Flow (cfs)		
			Mean	Harmonic Mean	7Q10
01636210	Happy Creek at Front Royal, VA	14	13.82	2.02	0.17
01636500	Shenandoah River, Millville, WV	3,040	2,685	1,262	377
01634000	N.F. Shenandoah River	768	58	236	65
01631000	S.F. Shenandoah River, Front Royal, VA	1,642	1,602	7,741	254

Source: USGS, period of record: 1930-1999.

USGS01631000 gauging station, located a few meters upstream of the impaired segment, appears to have sufficient data to establish an approximate flow balance. A seasonal flow analysis for this specific gauging station is presented in Table 2-3.

Table 2-3: Seasonal Flow Analysis at USGS 1631000

Time Period	Flow (cfs)		
Month	**Mean**	**Minimum**	**Maximum**
January	1,404	454	5,040
February	2,431	663	10,200
March	1,863	462	3,920
April	2,821	543	7,370
May	1,772	444	4,650
June	1,014	335	2,530
July	611	272	1,220
August	750	291	2,460
September	647	382	1,860
October	1,040	302	6,310
November	1,014	388	2,960
December	2,314	356	6,950

Source: USGS, period of record 1968-1993.

2.2. Water Quality Data

To characterize water quality conditions in the Shenandoah River, a number of data sources were investigated: EPA's STORET database (which contains water quality monitoring data from multiple agencies), the EPA Superfund database management system, EPA Region 3, West Virginia Department of Natural Resouces, West Virginia Department of Environmental Protection, Virginia Department of Environmental Quality (VADEQ), Virginia State Water Control Board (VASWCB), and U.S. Army Corps of Engineers. Figure 2-1 presents the water quality monitoring stations within the Shenandoah River basin.

The available data represent four sample media: clams, sediment, fish, and the water column. Figures 2-2, 2-3, and 2-4 illustrate the locations of the sediment, water column, and fish/clam monitoring sites from the agencies listed above. Data for the drainage area or the Shenandoah River were available for 1971 through 1999. Despite the large number of monitoring stations present in the watershed, the majority of the data are flagged as nondetect or below detection level (Table 2-4).

Table 2-4: In-stream Water Quality Overview

Sample Type	No. Samples	below detection limit (%)	above detection limit (%)	Detection Limit
Water	160	99	1	0.02-0.1 Fg/L
Sediment	490	97	3	1-1000 Fg/L
Fish Tissue	889	64	36	0.1-4.89 mg/Kg

2.2.1. Water Column Data

Ninety-nine percent of water column samples are nondetects or below detection levels. The laboratory detection limits were higher than both the West Virginia total PCB water quality criterion of 0.044 ng/L and the Virginia Aroclor water quality criterion of 0.44 ng/L. Therefore, the data may not have recorded violations of the water quality criteria.

Available data for samples above detection levels are very sparse, both spatially and temporally (Table 2-5, Figure 2-5). Appendix A-2 contains a detailed summary of available data, showing the spatial and temporal variability, and is presented in by source and media.

Table 2-5: Detectable Water Column Data

Station	Location	Date	Total PCBs (Fg/L)	Total PCBs (ng/L)
1BHKS006.23	Route 675 Bridge in Luray	06/06/1971	0.16	160
1BSHN038.27	Route 50 Bridge	05/02/1971	0.10	100

Note: Aroclor Water Quality Criteria 0.44ng/L.
Source: Virginia State Water Control Board.

The level of detectable PCBs in the water column are roughly 230 times greater than the Virginia Aroclor criterion of 0.44 ng/L. No water column samples with detectable PCB level were found in the West Virginia sites.

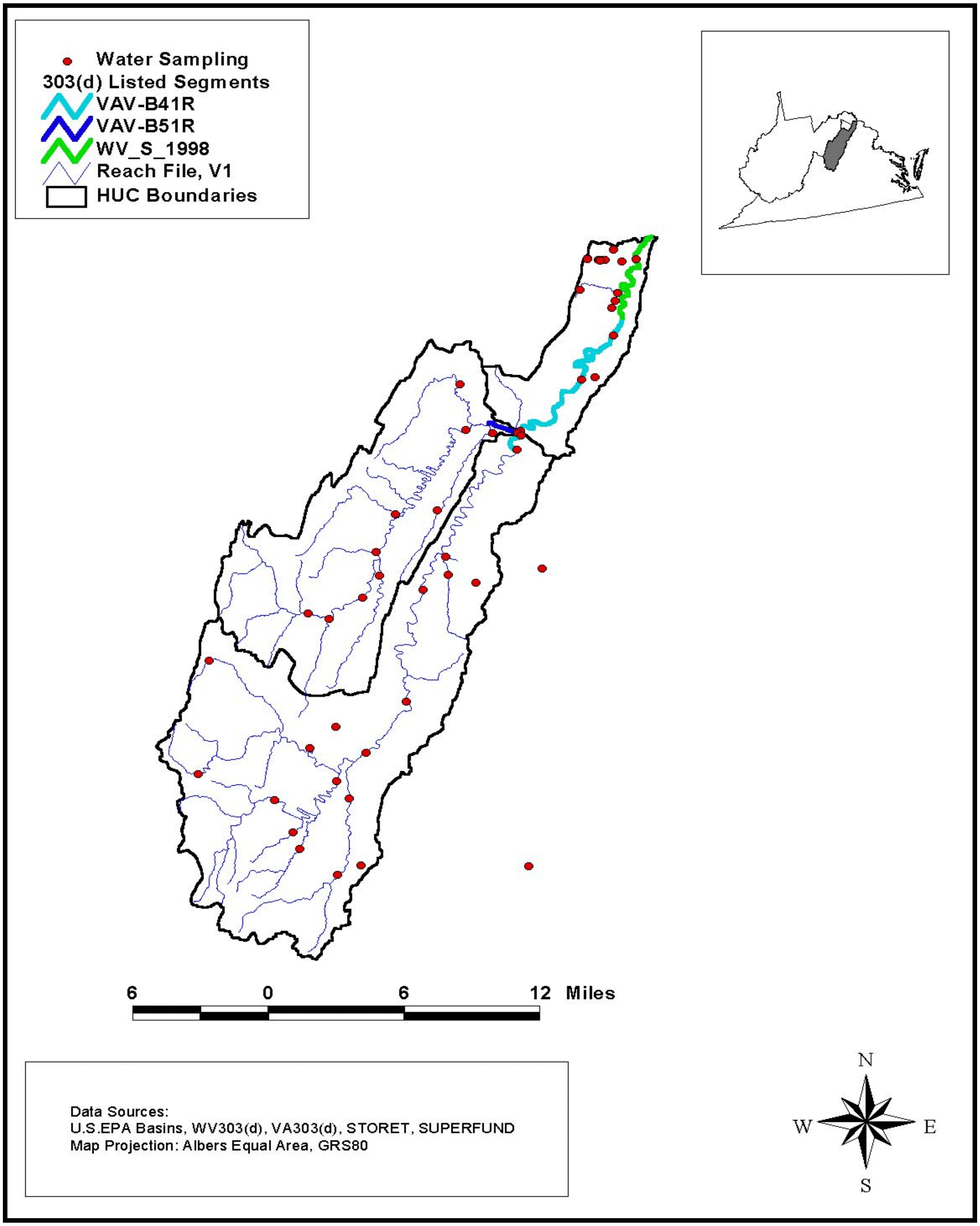

Figure 2-2: Sediment Sampling Locations from Multiple Agencies

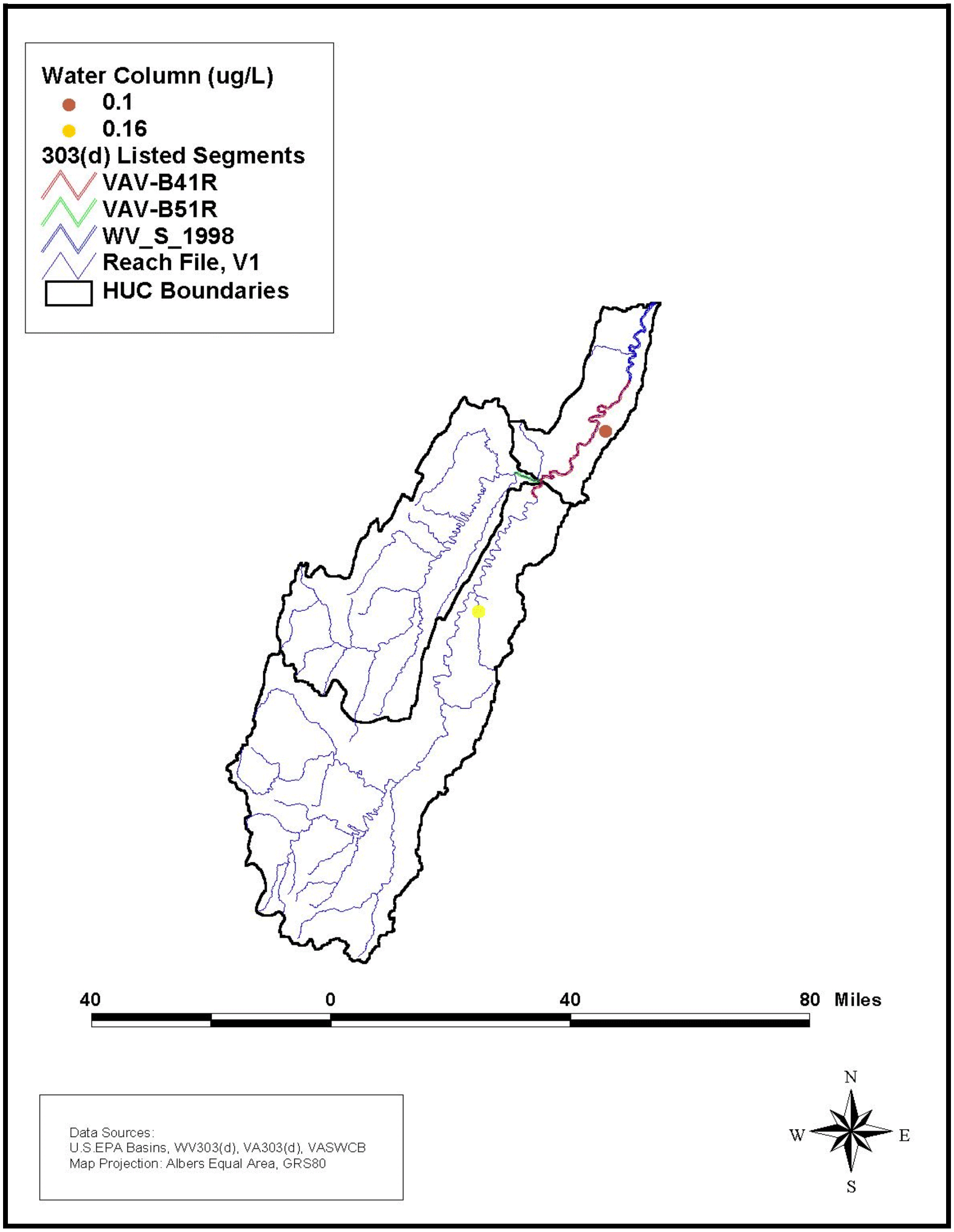

Figure 2-3: Detected PCBs in Water Column Samples

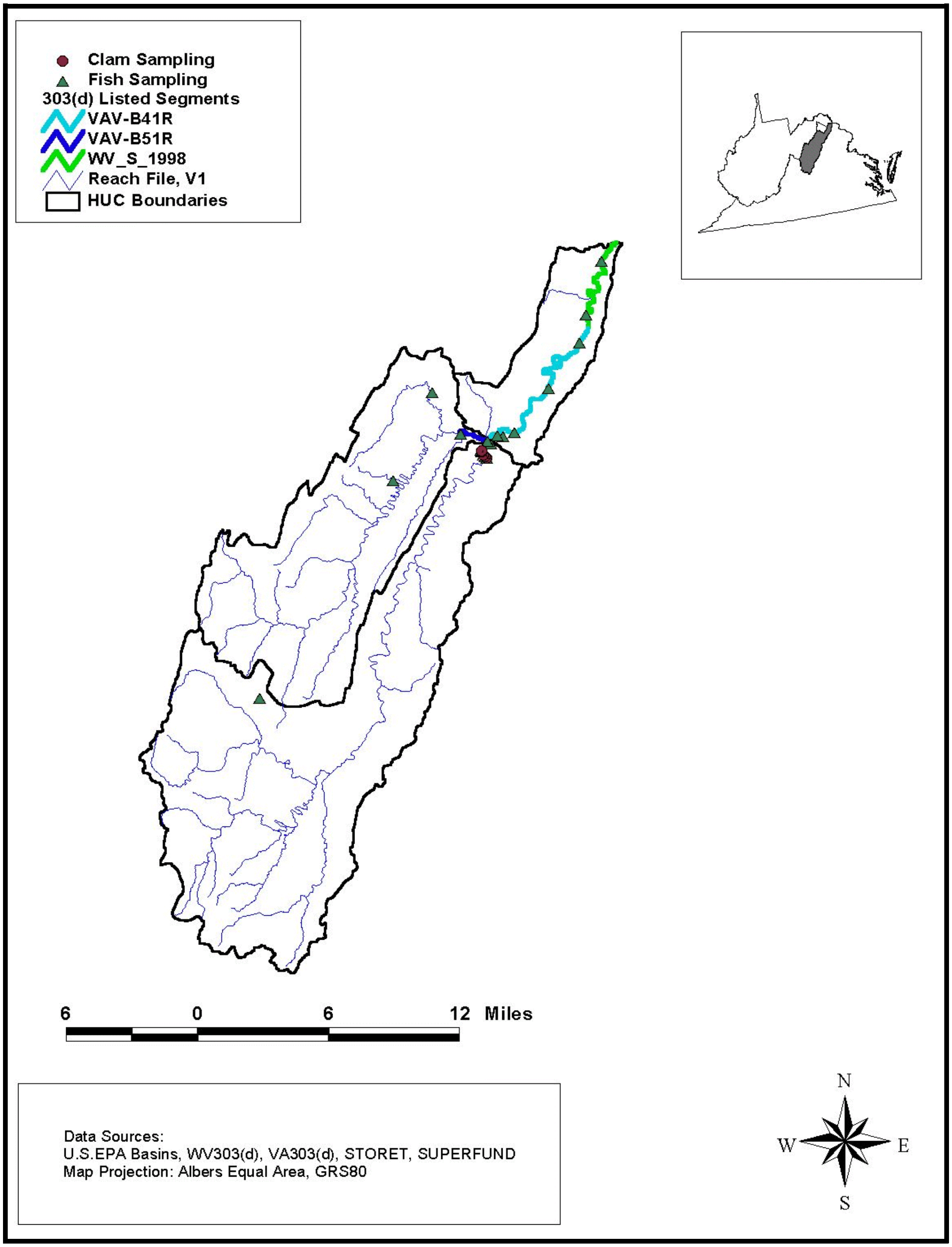

Figure 2-4: Clam and Fish Sampling Locations from Multiple Agencies

2.2.2. Fish Tissue Data

Eighty-six percent of the fish tissue samples were qualified. Approximately 5 percent of the fish tissue samples were found to exceed the 2 mg/kg FDA fish advisory criterion. Figure 2-5 illustrates the variability of PCB concentrations in fish tissue over time. The highest concentrations were found in the late 1980s, and most likely reflect the accidental discharge of PCBs into the Shenandoah River at that time.

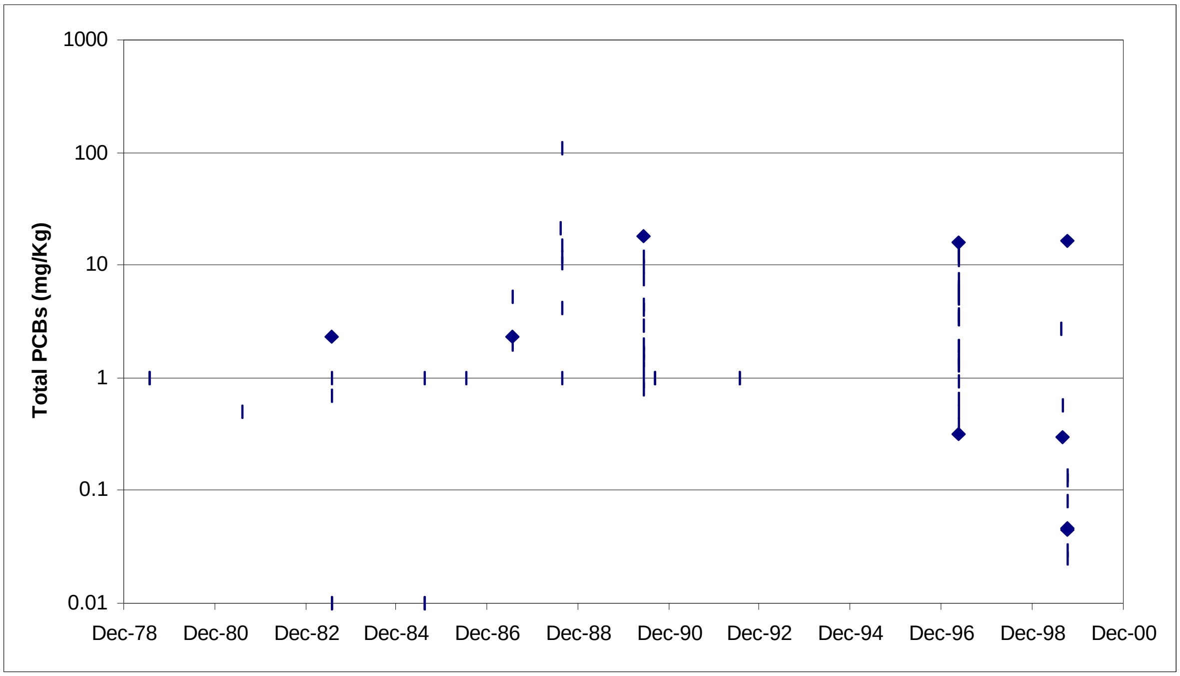

Figure 2-5: Total PCBs Concentration in Fish Tissue
Sources: STORET, WVDEP, Superfund, and VADEQ.

2.2.3. Sediment Data

The sediment results show that 97 percent of the data are below detection limits. Sample levels above the detection limit were found both in lakes within the drainage area and in main stem portions of the Shenandoah River. The total PCBs concentrations shown in Figure 2-6 were reported as the detection levels of 1 to 1000 Fg/kg instead of actual readings.

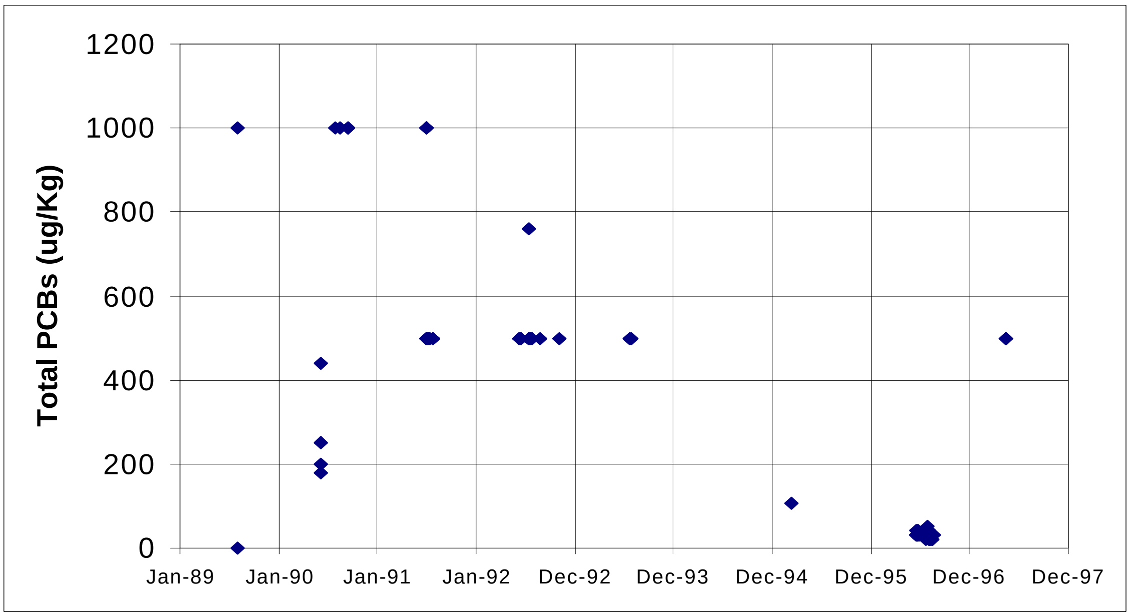

Figure 2-6: Total PCBs Concentration in Sediments
Sources: STORET, WVDEP, Superfund, and VADEQ.

2.2.4. Clam Tissue Data

The clam data collected by EPA's Superfund program in 1997 show that 43 percent of all samples were flagged, referring to the quality of data reported, (Table 2-6). Converting the µg/kg detection limits to mg/kg gives a range of 0.068 to 0.083 mg/kg respectively. The range of results for the µg/kg data is 0.1 mg/kg to 16 mg/kg.

Table 2-6: Superfund Data- Clams Type

Units	Count	Minimum	Maximum	Comments
mg/kg	30	0.320	16	
µg/kg	23	100	16000	All flagged, detection limits between 68 and 83.

As discussed earlier, most of the monitoring data were reported as nondetects because of the detection limits. Because there were so few actual readings, particularly in the water column, an additional sampling event took place in April 2001 to better quantify source contributions and the variability of PCBs throughout different media in the Shenandoah River watershed. The goal of this effort was to collect more samples using a lower detection level with a more complex analytical method. Multimedia samples (clams, water, and sediments) were collected at several locations within the Shenandoah River. Section 4 provides more detail regarding the sampling event and the additional PCB data.

Section 3: Source Assessment

This section identifies and examines the potential nonpoint and point sources of PCBs in the Shenandoah River watershed. A wide range of information was accessed to identify potential PCB sources and to characterize contributions, including monitoring data, Resource Conservation and Recovery Act (RCRA) database, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) database, Toxic Substance Control Act (TSCA) database, and Permit Compliance System database. This section is presented in two subsections - nonpoint source analysis and point sources analysis.

Polychlorinated biphenyls are synthetic compounds that are primarily found in electrical transformers. In 1976 manufacturing of PCBs was prohibited and strict tracking was instituted (GE, 1999). Although it is now illegal to manufacture, distribute, or use PCBs, these synthetic oils were used for many years as insulating fluids in electrical transformers and in other products such as cutting oils (GE, 1999). Historically, PCBs have been introduced into the environment through discharges from point sources and through spills and releases. Although point source contributions are now controlled, historical nonpoint sources may exist; for example, refuse sites and abandoned facilities.

Once in a waterbody, PCBs become associated with solid particles and typically enter sediments (Wisconsin DNR, 1997). PCBs are very resistant to breakdown and thus remain in river and lake sediments for many years.

3.1. Nonpoint Source Analysis

Nonpoint source loading of pollutants results from the transport of pollutants into receiving waters via landscape runoff processes, including overland and subsurface flow. Nonpoint sources of PCBs can be grouped most appropriately into nonpoint source media: washoff from land surfaces, and streambed sediments.

3.1.1. Washoff from Land surfaces

There are no natural sources of PCBs; however, PCBs can be found in many environments as a result of fires, historical spills, and airborne transportation of contaminated dust (atmospheric deposition). Usually, these PCB concentrations are well below EPA's action level of 1 ppm in soils.

Because PCBs are generally found in cooling oils, the affinity of PCBs for water is very low (USGS, 1995). PCBs have a high sorption factor for solids and fatty animal tissue. In the case of a fire, for example, PCBs can sorb onto smoke and ash particles and be scattered by the wind. PCBs from spills tend to remain in the area adjacent to the spill by sorbing to soil particles. These contaminated soils can then be transported through precipitation and overland flow to stream systems. This report incorporates the PCB concentration from surface lands into the streambed sediments concentration. Additional sampling in the Shenandoah River might help identify additional nonpoint sources.

Based on the sampling data, it appears as though the Warren County Landfill on Catlet Mountain Road in Front Royal, Virginia may be a source of PCBs to the Shenandoah River. The sampling data will be forwarded to EPA's Hazardous Site Cleanup Division, the Town of Front Royal, and Warren County for further assessment. EPA has requested records from both the County and Township on the closure of this facility.

3.1.2. Streambed Sediments

When PCBs spill and sorb onto the soil, there is a potential for stream contamination when precipitation washes the contaminated soil into the stream. The affinity of PCBs for soil would limit the effectiveness of groundwater seepage as a mode of transport. Discharges of PCBs directly into the stream can also result in sediment and stream bank contamination. The PCBs in discharges sorb onto the soils on the stream banks and onto the sediments downstream of the discharge point. Stream bank erosion deposits the contaminated soils in the streambed.

Contaminated streambed sediments are available for consumption by the aquatic biota (through dissolved particles or resuspended particles), are transported downstream, or are buried under additional sediments. The transport can result in the sediment being flushed out of the system or being trapped behind downstream dams. Existing PCB projects such as the Hudson River project in New York and the Housatonic River project in Massachusetts have found that historical discharges have resulted in sediment contamination and that the contaminated soils tend to collect in slow river stretches or reservoirs (GE, 1999). The contaminated soils remain there until they are dredged or dislodged by storms. Figure 3-1 illustrates the interaction among PCBs, sediments, and the water column.

Figure 3-1: Water-Sediment Interaction

As discussed in the Data Assessment section, the existing data available for the Shenandoah River do not contain sufficient sediment samples above detection limits to allow temporal or spatial predictions. Stream sediments represent the most likely source of PCBs currently and in the future. The discussion of the Avtex Fiber site (section 3.2.1) explains this in more detail. Additional sediment sampling using lower detection limits would help identify hot spots of PCB contamination in the Shenandoah River.

The sorption of PCBs onto sediment represents a critical mechanism for uptake into the food chain. Fish and benthic organisms are exposed to and accumulate PCBs from the water, through contact with and ingestion of sediments, and from the food they eat. Bottom-feeding fish like carp accumulate high concentrations because of their consumption of contaminated detritus and sediments. As bigger fish or mammals eat smaller contaminated fish, the PCBs bioaccumulate in the fatty tissues. When the animals die, the accumulated PCBs are released to the soil or water. Migration of fish from contaminated areas to clean areas can spread PCBs into new areas. Tissue concentrations vary based on the animal s travel range, age, weight, and diet. Concentrations are extremely variable even within the same species and at the same location.

3.2. Point Source Analysis

A point sources are defined in the Clean Water Act as any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged (USEPA, 1995). Common point sources are effluent discharges from municipal and industrial wastewater treatment plants.

The majority of PCBs discharged into the Shenandoah River have been attributed to Avtex Fibers, Inc. which was active from the 1940s to the late 1980s. Virginia s 1998 Section 303(d) list identified Avtex Fibers as the source of PCBs to the Shenandoah River primarily because of contamination associated with an electrical transformer explosion. The PCBs in the Shenandoah River are believed to have accumulated in the sediments, particularly after the explosion.

3.2.1. Avtex Fibers, Inc.

Avtex Fibers, Inc. is located on Kendrick Lane in Front Royal, Virginia, adjacent to the South Fork of the Shenandoah River. This site has a long history and VADEQ and WVDEP have identified it as a historical source of PCBs. The site history is available from many documents in the EPA Superfund Document Management System (SDMS).

3.2.1.1. Site Description

The 440 acre site is bordered by residences to the south and east, Allied Chemical to the north, and the North Fork of the Shenandoah river to the west. The Shenandoah National Park is located 1 mile upstream of the facility and has not been affected by the site. The site elevation ranges from 560 feet MSL on the east to 480 feet MSL at the western edge along the river bank. The mean river elevation is 470 feet MSL, while the 100 year flood plain extends to 490 feet MSL. The Avtex site contains five settling basins, which are used to store storm water. They range from 480 to 490 feet MSL and are subject to flooding. A 1999 report (ERM, 1999; SDMS 146745) confirms this problem. The wastewater treatment plant and the lower settling basins were inundated in January 1996 and September 1996.

3.2.1.2. Corporate History

The corporate history of the site began in 1940 when American Viscose began rayon production. In 1963 FMC Corporation bought the facility. By 1970 the plant began producing polyester as well, which was made until 1977. The on site treatment facility, referred to as the wastewater treatment plant (WWTP), was constructed in 1973. The facility was financed by industrial revenue bonds issued by the Industrial Development Authority of Front Royal and Warren County, Virginia (IDA). The WWTP was leased to FMC and subleased to Avtex in 1976.

On-site remediation projects started in 1982 when carbon disulfide was discovered in nearby drinking water wells. From 1985 to 1989, Avtex Fibers produced polypropylene. Water quality sampling in 1988 showed PCB contamination of fish, causing the Virginia State Water Control Board (VASWCB) to issue a fish consumption advisory. By fall 1989 legal hearings had started on revoking the water discharge permit (VA0002208)for the site. The permit covered four outfalls, the fly ash retention basin, fly ash stockpile, storm water and noncontact cooling, and the waste treatment system. On November 11, 1989, Avtex Fibers was closed and the company abandoned the facility. After Avtex filed for bankruptcy, USEPA Region 3 began emergency remediation to stabilize the site. Under legal orders, FMC became an active party in the remediation effort.

FMC s involvement with the CERCLA remediation at the site began in 1988, when it became a party to an Administrative Order on Consent to conduct an RI/FS, the purpose of which was to investigate ground water contamination resulting from viscose waste disposal. In April 1990, FMC took over operation of the WWTP from EPA, pursuant to and under the terms of an Administrative Order dated February 2, 1990. Until April 1990, FMC had not been the actual or legal operator of the WWTP since it sold the site to Avtex Fibers in 1976.

3.2.1.3. History of PCBs Contamination

Contamination at the site was caused by several different events. The fiber production process involved cellulose, sodium hydroxide, carbon disulfide, phenols, sulfuric acid, sodium sulfate, zinc salts, and sodium hypochlorite. The site remediation project involved at least 25 solid waste disposal areas that contained fly ash, boiler solids, inferior viscose, and sludges. Viscose is an intermediate product of the manufacturing process. The sludge came primarily from the waste treatment system s primary settling tanks and clarifiers. This sludge was stored in the sulfate basins, which is a misnomer. Zinc was important to the fiber spinning process, so the high-zinc-content sludge was frequently reclaimed. When EPA began stabilizing the site in 1989, the wastes removed from the site included carbon disulfide, sulfuric acid, chlorine gas, dimethylamine, sodium hydroxide, picric acid, other chemicals that ignite through flame or motion shock, sludge containing carbon disulfide, and water containing carbon disulfide. The wastes from the fiber production and spinning are not the source of PCBs to the Shenandoah River.

The fiber production process did involve a drying process, which involved the use of PCBs. The Abbe dryers that were used to remove water from wet polyester chips used a heat transfer fluid during the drying process. During the CERCLA information gathering, the company supplied information about the Abbe dryers (SDMS Document 268429). The original fluid was Therminol FR-O, which contained Aroclor 1242. By February 1972 FMC had drained the system and refilled it with Therminol 55, which did not contain PCBs. Strong evidence exists that the dryers leaked, including a 1976 operations manual that detailed heating system pump failures indicated by leaking pump seals or large amounts of fumes. A 1972 memo discussed installing drip pans because Therminol 55 was not fire-resistant like the Therminol FR-O. A 1972 memo also detailed a sewer line to be installed to redirect Therminol drainage from the rainwater drain to the treatment system. The dryer system contained PCBs for at least a decade after the flushing and change from FR-O. A 1982 sample contained 3100 ppm of Aroclor 1242. A sample from 1984 contained 46 ppm of Aroclor 1242. Early use of the dryer resulted in spills onto the concrete pad holding the heating fluid boiler and circulation system and resulted in soil contamination.

The second source of PCB contamination is electrical equipment used on the site. One of the principal uses of PCBs has been as a coolant in electrical transformers and capacitors. According to the regulations, all transformers and capacitors that are intact, with no leakage or PCB oils on the exterior surface may remain in service. Leaking transformers must be removed from service and properly transported to a hazardous waste facility. Items containing oil or having PCB contamination that exceeds 500 mg/L are considered PCB items. Items containing oil or having PCB contamination between 50 mg/L and 500 mg/L are usually considered PCB contaminated. If the PCB concentration is below 50 mg/L, the item is normally considered a non-PCB item. As of 1980 items containing PCBs in concentrations greater than 50 mg/L are required to be marked, and proper records of all marked items must be kept on-site. (40 CFR Chapter 1 Part 761, July 1, 2000).

The electrical load for the Avtex site required electrical transformers and capacitors to regulate the demands. An inspection on June 22, 1989, found 19 transformers and 73 capacitors. Several transformers showed evidence of leakage onto concrete pads or the ground. At some point while Avtex was still in operation, a rooftop transformer exploded and the soils surrounding the building became contaminated with Aroclor 1260. The entire Avtex site is underlain by a complex drain system that is more than 40 years old. The process sewer and storm sewer lines frequently cross and leakage between the two systems could spread PCB-contaminated soils throughout the site and into the waste treatment system. That this had occurred was confirmed in the CERCLA Remedial Investigation (SDMS 135739). The sewers were in disrepair, and the storm sewer directly discharged through Outfall 003 until November 1989 when EPA redirected the flow to Sulfate Basin 1. The 1989 clean-up process found PCB-contaminated sediments in the storm drain system.

3.2.1.4. Site Remediation

The site remediation history is complicated. Although contamination was found throughout the property, the largest sources were found in the vicinity of several buildings, drainage ditches, sulfate basins, and the wastewater treatment plant (WWTP). The first Record of Decision (ROD) was issued for Carbon Disulfide affecting nearby drinking water wells. EPA directed the implementation of ROD 1 be postponed indefinitely after it decided to conduct a site-wide RI/FS. The second ROD was issued in 1990, about a year after Avtex ceased operations at the facility. It was not limited to PCBs, but contained four components, one of which was excavation and disposal of approximately 5,000 cubic yards of PCB-contaminated soil, and problems related to leaking transformers and the transformer that had exploded. The PCB leakage from the Abbe dryer system was discovered at this time. The subsequent abandonment of the site by Avtex effectively combined the two RODs. For example, the efforts to characterize the sewer system resulted in a clean-up effort for viscose clogs, carbon disulfide, hydrogen sulfide, and PCBs. On September 29, 1989, the storm drain system was plugged using an inflatable rubber bladder. By October 30, 1989, contractors had removed 8 cubic yards of sediment from the sewer system. Several sewer sections required three rounds of steam cleaning to meet the 1 ppm standard for surface wipes of the pipe walls. On January 30, 1990, a rainstorm resulted in the rubber bladders failing, releasing 1.5 million gallons of water to the river. By February 7, 1990, a permanent concrete plug was installed in the storm sewer system, diverting all flows to the sulfate basins and the WWTP. Contaminated soil from the site could possibly reach the River via surface runoff. However, the likelihood of this has been significantly reduced since runoff from the entire plant, including PCB impacted areas, is controlled through the diversion of storm water to Sulfate Basin 1.

Sampling in March 1990 showed one of nine samples was above detection limits. That reading was 0.216 mg/kg. Three samples were taken from the emergency lagoon for the treatment plant; one was below detection and the other two measured 0.161 mg/kg and 0.220 mg/kg. According to SDMS 135739, 8,000 cubic yards of soil were removed from the area surrounding the transformer explosion and the polypropylene building and loading dock. The concrete pad and roof where the transformer were located were demolished. During a September 1989 survey, oily sediment samples from the roofs of the Avtex facility had PCB levels as high as 136,000 mg/kg, with an average value of 595 mg/kg. The roof where the transformer had exploded had an average value of 2,859 mg/kg. A water sample from Outfall 003 registered 163 µg/L. Water samples from various onsite sewers had PCB concentrations below 2.2 µg/L. Sewer sediments were below 2.7 mg/kg except for one sample that registered 15,000 mg/kg. The level of PCBs in Outfall 003 indicate the severity of PCB contamination. PCB levels below action targets were also detected in other areas, including the coal storage yard. The removal of the polypropylene loading dock revealed pooled liquid that had seeped from the building. Testing of sumps in the polypropylene building were positive for the presence of PCBs. A summary of the results of 21 samples from Outfall 004 collected during 11 sampling runs between September 29, 1989 and October 18, 1989 indicated levels of 0.3 and 1.0 µg/L for PCBs in the water. The 1989 VASWCB report summarizes the findings from sediment sampling conducted in the North Fork, South Fork, and main stem of the Shenandoah River. Sediment samples ranged from nondetect to 38.3 mg/kg. The highest readings were adjacent to the site, and readings diminished in the downstream direction. Samples upstream of Outfall 003 were below detection; the highest reading was 1,400 feet downstream of Outfall 004.

On July 20, 1992, the Avtex WWTP detected PCBs at 1.5 µg/L. The laboratory QA/QC was not available for this sample, but the on-site coordinator opted to discontinue the plant discharge and check the system. The on-site transformers and capacitors were inspected on December 8, and several transformers were observed to be leaking. Some transformers were located within 5 feet of roadside drains, drainage ditches, storm sewers, and other possible conveyance paths for spills.

A report by S.D. Meyers (Meyers , 1989) contains clean-up standards of below 1 ppm for the sewer pipes or below 1 mg per 100 square centimeters of area. Soil and surface remediation targets are below 10 mg/100 cm^2 or 10 mg/kg soil. The standards can be found in 40 CFR 761.125. The regulations also require all excavated soil to be replaced with clean soil containing less than 1 mg/kg of PCBs. The land contours must be restored to the greatest extent possible. The minimum soil cap as defined in 40 CFR 761.61(a)(7) is 10 inches.

Sampling was conducted between June 1993 and April 1994 throughout the site. In the vicinity of the polypropylene building, eight samples were collected: six surface samples and two subsurface samples. Four samples registered between 0.24 and 5.8 mg/kg. Samples from the landfill and fly ash piles showed 0.074 to 0.33 mg/kg and samples from all drainage ditches were below detection limits. Samples from the sulfate basins had 0.14 to 1 mg/kg while samples from the electrical transformer yard had 0.3 to 3.4 mg/kg. The highest readings were from the WWTP emergency overflow lagoon, where concentrations of 0.47 to 7.1 mg/kg of PCB were found. Sediment samples collected from the lagoon in May 1997 found

0.45 mg/kg of Aroclor 1254 and 0.4 mg/kg of Aroclor 1260. The polishing pond samples from that day contained 2.2 mg/kg of Aroclor 1254 and 3 mg/kg of Aroclor 1260. A river sediment sample collected just downstream of Outfall 004 contained 0.47 mg/kg. Aroclor 1248 and 1254 were detected in soil samples from the polypropylene building at concentrations of 0.084 and 0.34 mg/kg, respectively.

FMC collects and treats site stormwater pursuant to the Unilateral Administrative Order (UAO) corresponding to the U.S. Environmental Protection Agency (EPA) Docket No. III-90-21-DC, issued to FMC on February 2, 1990. Since the plant was closed in 1989, stormwater from the former plant area has been captured in the existing storm sewers and diverted into the sulfate basins, emergency lagoon and polishing basins, where it is retained prior to treatment. Stormwater is treated in the wastewater treatment plan (WWTP) to meet the discharge requirements set forth in the UAO prior to discharge through Outfall 004 into the South Fork of the Shenandoah River. Between circa 1991 and 1999, the WWTP was operated using chemical precipitation to treat zinc and a biological unit to treat organics. However, in 1999 FMC reconfigured the plant to use sand and bag filtration (nominal 1 micron) and carbon adsorption. The combination of filtration and carbon adsorption is used to treat the presence of PCBs in the form of microparticulates. This treatment approach is considered best available technology for the volume of water requiring daily treatment at the Avtex site, and has proven to be successful to meet the discharge limits of 0.5 ÿÿg/l for the individual PCB aroclors.

FMC is performing removal and remedial actions at the Avtex Site pursuant to the Consent Decree between the United States of America and FMC (effective 21 October 1999). Completion of these actions, which is scheduled to be complete by 2005, will effectively eliminate PCB sources on the Avtex property. Completion of these actions, which is scheduled to be complete by 2005, will effectively eliminate PCB sources on the Avtex property. The scope and anticipated schedule for these actions are described below.

" The remaining buildings will be decontaminated, which is starting in 2001 and will be completed in 2003. Decontamination will address PCB-contaminated surfaces present in the buildings.
" Contaminated soil in the former plant area will be capped and/or removed, which will be completed in 2004. Areas where PCB contamination is present in surface soil will be addressed during the plant area soil remediation.
" The process and storm sewers will be excavated or plugged. This action is expected to start in 2002 and be completed in 2003. Some of the sewers in the vicinity of the transformer explosion potentially contain PCBs.
" The fly ash basins and stockpile, and WWTP and sulfate basins are being closed. This action started in May 2001 and will be completed by the end of 2003. Some of these basins contained PCBs.
" The WWTP will be shutdown and demolished, sometime after 2004.

Upon the completion of the remediation project, EPA does not expect the site to be a source of PCBs and has therefore assigned a Load Allocation of zero to the site. However, the WLA will be transferred to the Margin of Safety to account for any uncertainty in the loadings.

3.2.2. Toxic Substance Control Act

Congress enacted the Toxic Substances Control Act (TSCA) of 1976 to give EPA the ability to track the 75,000 industrial chemicals currently produced or imported into the United States, including PCBs (http://www.epa.gov/region5/defs/html/tsca.htm). EPA repeatedly screens these chemicals and can require reporting or testing of those that may pose an environmental or human-health hazard. EPA can also ban the manufacture and import of those chemicals that pose an unreasonable risk (15 U.S.C. §§2601 et seq.[1976]). Additionally, mechanisms are in place to track the thousands of new chemicals with unknown or dangerous characteristics that industries develop each year. TSCA supplements other federal statutes, including the Clean Air Act and the Emergency Planning and Community Right-to-know Act (Toxic Release Inventory). Additional information on these programs is available from the USEPA, including the EPA web pages (http://www.epa.gov/region3/defs/html/tsca.htm).

The TSCA facility database was reviewed to find potential PCB sources in the Shenandoah River watershed, and no facilities were identified by EPA. At the present time, no facilities in the watershed handle PCBs and are required to submit reports of contact with PCBs.

3.2.3. Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act of 1976 (RCRA) gave EPA the authority to control hazardous waste "cradle to grave" (http://www.epa.gov/region5/defs/html/rcra.htm). This control includes the generation, transportation, treatment, storage, and disposal of hazardous waste. RCRA also sets forth a framework for the management of nonhazardous waste. The 1986 amendments to RCRA enabled EPA to address environmental problems that could result from underground tanks storing petroleum and other hazardous substances. RCRA focuses only on active and future facilities and does not address abandoned or historical sites. According to the EPA RCRA Information System (RCRIS) records, the Shenandoah watershed contains six RCRA sites: DuPont, Wilson Jones, General Electric (Winchester), Merck & Co, Genicom, and Wagner Electric (Table 3-1). None of these facilities were found to be a possible source of PCB contamination in the Shenandoah River watershed. Refer to Appendix B-1 for detailed information about each RCRA site.

Table 3-1: RCRA Facilities

Facility ID	Name	Pollutants	City, State
VAD003124989	Wilson Jones	N/A	Crozet, VA
VAD070360219	G.E. Winchester Corp.	Fuel storage (underground storage tanks)	Winchester, VA
VAD001705110	Merk Stonewall	Acetone, toluene, Volatile compounds, phenol, naphthalene, carbon tetrachloride	Elkton, VA
VAD003132438	Genicom	Trichloroethylene	Waynesboro, VA
VAD003070976	Wagner Electric	Asbestos, metals	Winchester, VA
VAD003114832	Dupont Waynesboro	Volatile organic compounds, Semivolatile organic compounds, Mercury	Waynesboro, VA
VAD003125770	Koppers Industry	Creosote, Polyaromatic hydrocarbons, Volatile organic hydrocarbons	Salem, VA

Source: RCRA Database

3.2.4. Comprehensive Environmental Response, Compensation, and Liability Act

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) provides a federal Superfund to clean up uncontrolled or abandoned hazardous waste sites, as well as accidents, spills, and other emergency releases of pollutants and contaminants into the environment (http://www.epa.gov/superfund/sites/npl/npl.htm). Through the act, EPA was given power to seek out those parties responsible for any release and ensure their cooperation in the cleanup.

EPA cleans up orphan sites when potentially responsible parties cannot be identified or located or when they fail to act. EPA obtains private party cleanup through various enforcement tools such as court orders, consent decrees, and other small party settlements. EPA also recovers costs from financially viable individuals and companies once a response action has been completed (http://www.epa.gov/superfund/sites/npl/npl.htm). After a site investigation shows no pollutants or shows that remediation standards have been met, the site is deleted from the active list and is placed on a list for No Further Remedial Action Planned (NFRAP).

EPA is authorized to implement CERCLA in all 50 states and the U.S. territories. Superfund site identification, monitoring, and response activities in states are coordinated through the state environmental protection or waste management agencies (42 U.S.C. §§ 6901 et seq. [1976]).

EPA personnel searched CERCLIS (the CERCLA Information System) for sites in Clarke, Page, Rappahannock, Shenandoah, and Warren counties. There were no sites found in Rappahannock County. A total of 12 sites were identified in CERCLIS in the other counties(Table 3-2). Except for Avtex Fibers, Inc., none of these facilities were found to be a significant source of PCB contamination into the Shenandoah River watershed. The Warren County Landfill, located near the South Fork of the Shenandoah River, could be a potential source of PCBs. Further investigation is required to address this landfill. Refer to Appendix B-2 for detailed information about each of the CERCLA sites.

Table 3-2: CERCLA Sites

EPA Facility ID	Name	City, State
VAD980551691	BFI Kwik Klean Landfill	Berryville, VA
VAD980551634	Stauffer Chemical Company	Bentonville, VA
VAD980831044	Warren County Landfill	Bentonville, VA
VAD988228789	Racon Dump Site	Winchester, VA
VA0002333839	Aspen Hills Quarry	Front Royal, VA
VAD003064003	Allied Chemical Corp.	Front Royal, VA
VAD980551576	Page County Landfill	Stanley, VA
VAD001467778	Virginia Oak Tannery	Luray, VA
VAD000799395	Chemstone Corp.	Strasburg, VA
VAD000019620	Genie Corp.	Shenandoah, VA
VASFN0305571	Foster Lab	Shenandoah, VA
VAD070358684	Avtex Fibers, Inc.	Front Royal, VA

Source: CERCLIS.

3.2.5. EPA Permit Com11pliance System and Industrial Facility Discharge

A review of the EPA Permit Compliance System (PCS) shows 140 major, permitted facilities in the watershed (Figure 3-2). (See Appendix C). Of the 140 facilities, there are no power/electric generators. Pulp and paper mills are sometimes required to monitor for PCBs. There is one paper mill in the watershed; however, the mill s current list of monitoring parameters does not include PCBs. The Industrial Facility Discharge (IFD) database was also reviewed for facilities within the watershed, and 100 industrial facilities were identified (See Appendix C). These are permitted surface water discharges that have a small flow and are not expected to significantly affect the waters. Based on Standard Industrial Classification codes, there is one power generator in the watershed, Potomac Edison Power. No permit limits or monitoring data were identified to support including Potomac Edison as a PCB source. No other potential point sources were identified based on these data sources.

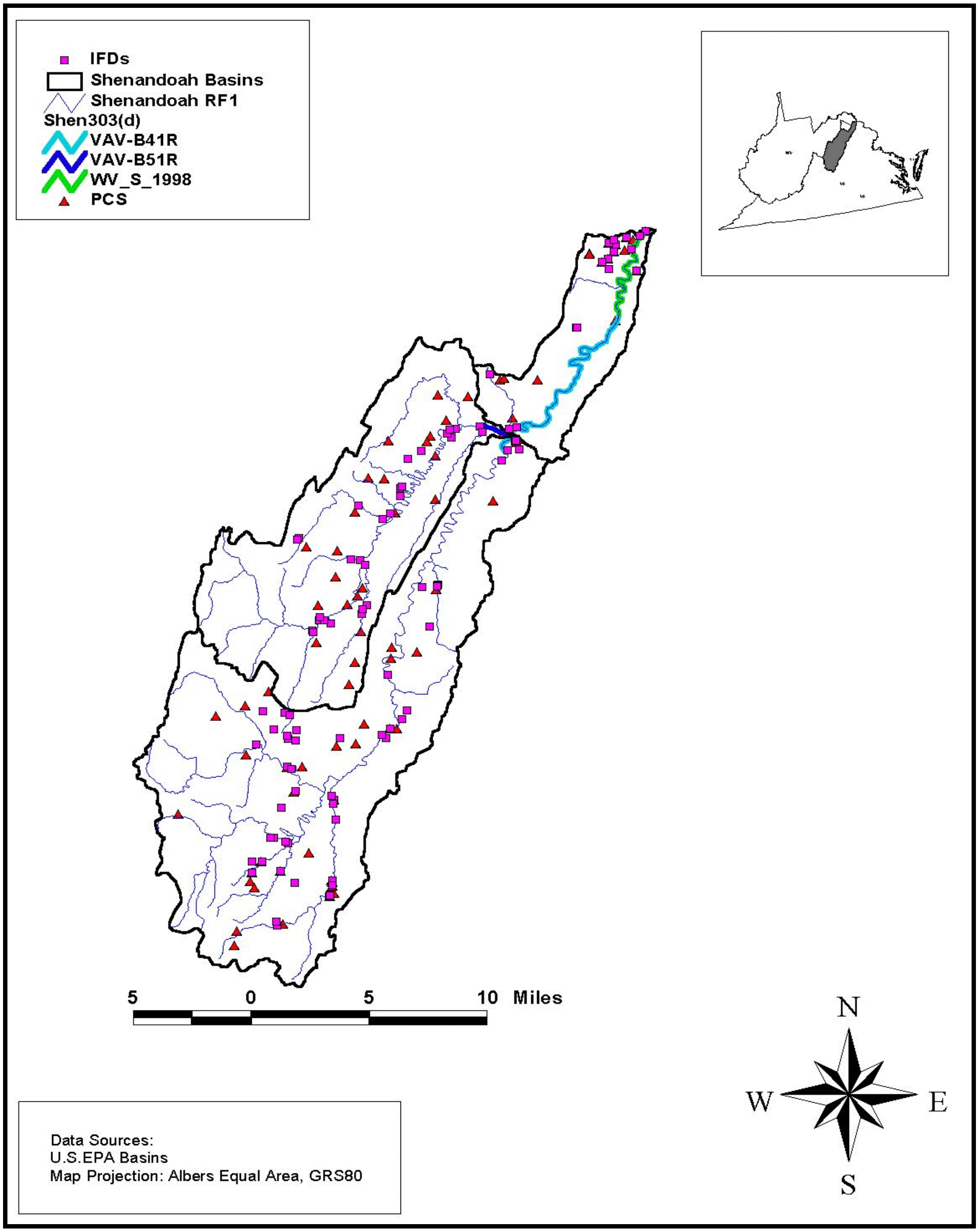

Figure 3-2: PCS and IFD Facilities in the Shenandoah River Basin

Section 4: Supplemental PCB Sampling in Shenandoah River

The existing PCB data for the Shenandoah River documented conditions at or near Avtex Fibers, Inc. Most of the existing data, based on Aroclor analyses, failed to indicate the detection of PCBs in either sediment or surface water. Additional sampling data were therefore warranted, to gain a better understanding of the pollutant loading to the stream.

A sampling event was conducted from April 26 through April 29, 2001, to support a more in-depth assessment of the spatial variation of PCBs in the Shenandoah watershed and to identify additional potential sources. The objectives of the additional sampling were as follows:

1. Determine the magnitude and extent of PCB contamination in the Shenandoah River.
2. Identify current hot spots and potential sources of the PCB impairment in the Shenandoah River.
3. Investigate historical point sources of PCBs (Avtex Fibers, Inc.).
4. Develop water/fish and water/sediment ratios, because historical readings were above detection.
5. Identify correlations between the water column, sediments, and biota data. In most cases where multi-media samples were collected, detection limits for one or more media resulted in levels below the detection limit. By collecting simultaneous samples of the various media, PCB concentration ratios can be determined for water versus fish, water versus sediment, and fish versus sediment concentrations.

The sampling stations listed in Table 4-1 were selected based on the 1997 Superfund sampling locations, STORET stations, and recommendations made through the public participation process. In addition to spatial comparison, the 12 sites presented in Figure 4-1 permit temporal comparison to existing data. The sampling sites cover the South Fork of the Shenandoah River below the former Avtex facility to the main stem of the Shenandoah River below the Potomac Edison dam near Warren, with one sample from the North Fork of the Shenandoah River upstream of its mouth, a sample from Happy Creek just upstream of its mouth, a sample from Dog Run just upstream of its mouth, and one sample from the impoundment near Millville Dam (West Virginia). To obtain the lower detection limits needed for this study, EPA Method 1668A, which analyzes all 209 PCB congeners, was used.

Refer to Appendix D- for detailed information about the Quality Assurance Project Plan (QAPP) for the Shenandoah River PCB TMDL sampling event. The QAPP provides general descriptions of the work performed to collect and analyze the samples, health and safety considerations, standard operating procedures, laboratory qualifications, and data validation requirements.

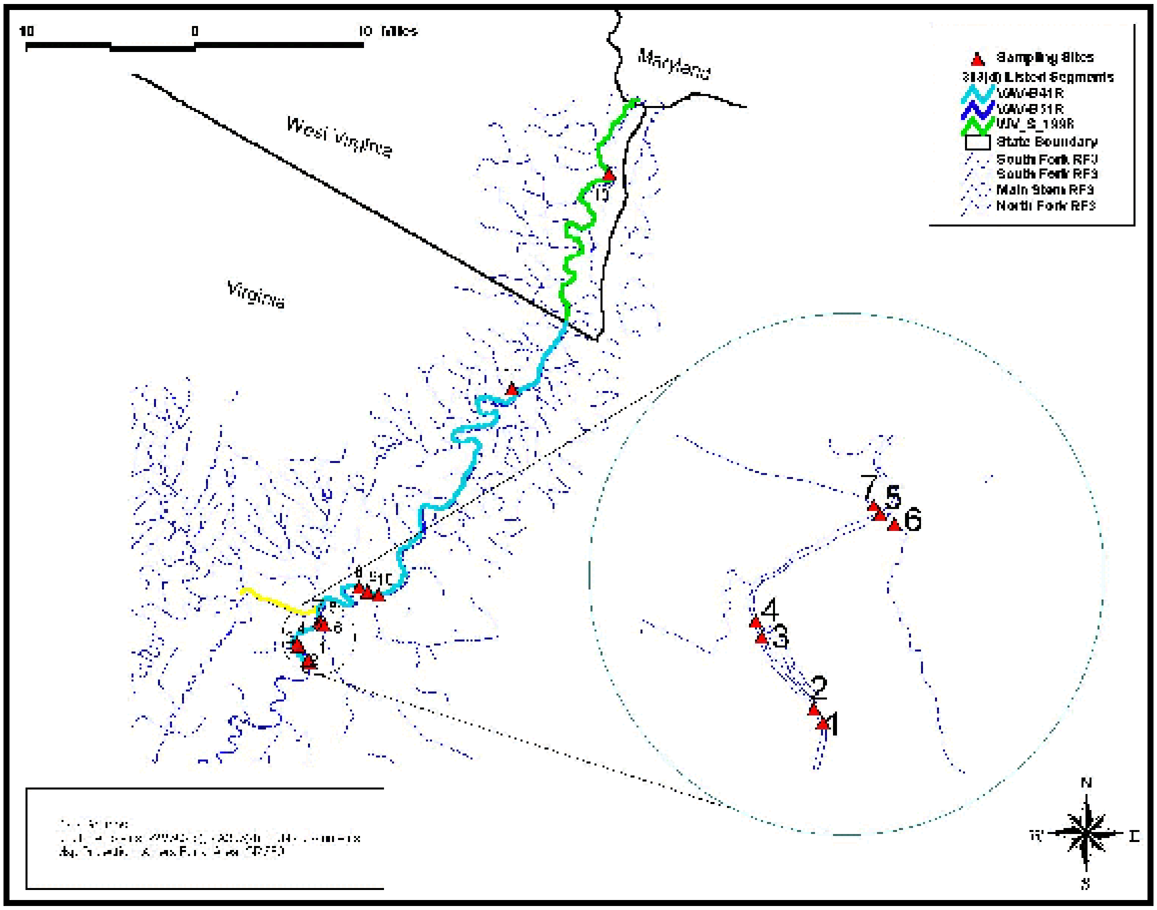

Figure 4-1: Sampling Site Location Map

4.1. Sampling Event

The sampling event took place from Thursday April 26, 2001 through Sunday April 29, 2001. Site 8 was removed because no runoff was identified from the old Riverton Power Plant. Clams were found in only 2 of the 12 sampling locations.

Table 4-1 lists the total number of samples collected during the sampling event. Photographs documenting the sampling event are provided in Appendix E.

Table 4-1: Summary of Samples Collected During Sampling Event April 26-29, 2001

Sampling Point	Sampling Point Description	Matrices	Number of Samples to Be Analyzed: PCBs (water, clams, sediment)	Number of Samples to Be Analyzed: TSS (water only)
1	USGS (Gauge 01631000), S.F Shenandoah River	Water, sediment	2	1
2	Warren County Landfill contribution into S.F. Shenandoah River	Water, sediment	2	1
3	Avtex WWTP	Water	1	1
4	Downstream of Avtex, S.F. Shenandoah River	Water, clams, sediment	3	1
5	South Fork, upstream of the confluence with N.F. Shenandoah and Happy Cr.	Water, sediment	2	1
6	Happy Creek	Water, clams, sediment	3	1
7	N.F. Shenandoah River	Water, sediment	2	1
9	Downstream of Potomac Edison Riverton, S.F. Shenandoah River	Water, sediment	2	1
10	Power pool dam, main stem Shenandoah River	Water, sediment	2	1
11	Dog Run	Water, sediment	2	1
12	Millville Dam, West Virginia, main stem Shenandoah River	Water, sediment	2	1
Field duplicates Site 7	N.F. Shenandoah River	Water, sediment	2	1
Subtotal Number of Samples Per Analyte			25	12
Total Number of Samples				37

Note: USGS = U.S. Geological Survey, WWTP = wastewater treatment plant, PCBs = polychlorinated biphenyls, TSS = total suspended solids.

4.2. Preliminary Validated Total PCBs Results

Table 4-2 lists validated results for water column samples, two tissue samples, and sediment samples.

Table 4-2: Total PCBs Concentration Data

Sampling Point	Description	Water[a] (pg/L)	Tissue[a] (ng/kg)	Sediment[a] (ng/kg)	TSS (mg/L)
1	USGS (Gauge 01631000), S.F. Shenandoah	10.6	-	310.0	6.3
2	Warren County Landfill contribution into S.F. Shenandoah River	1487.0	-	37855.0	23.0
3	Avtex WWTP	28200.0	-	-	17.0
4	Downstream of Avtex, S.F. Shenandoah	16.9	3360.0	1029.0	7.6
5	S.F. Shenandoah, upstream of the confluence with North Fork and Happy Creek	21.4	-	100000.0	6.0
6	Happy Creek	46.4	14000.0	13100.0	2.4
7	N.F. Shenandoah	12.9	-	4082.0	4.0
9	Downstream of Potomac Edison Riverton, S.F. Shenandoah	8.9	-	11024.0	4.7
10	Power pool dam, main stem Shenandoah River	30.0	-	7154.0	4.6
11	Dog Run	7.7	-	2592.0	26.0
12	Millville Dam, West Virginia, Shenandoah River	79.1	-	17367.0	9.5
Field Duplicate	N.F. Shenandoah	1361.0	-	19223.0	3.7
Blank	Lab blank	117.0	28.0	16.7	-

[a] validated data

Section 5: TMDL Technical Approach

This section of the document outlines the approach used to determine the TMDL for PCBs for the Shenandoah River. The approach utilizes available information on the hydrology of the river system, PCB data from a recent sampling event, and information on the fate and transport of PCBs in a river.

5.1. Source-Response Linkage

5.1.1. Model Development

In order to represent the linkage between source contributions and in-stream response for the Shenandoah River, an analytical model was developed. The model was developed to represent a simplified mass balance for the system, i.e. simulate input and transfer of PCBs in the river. A mass balance is a convenient way of defining what occurs within the Shenandoah River as a function of time.

The predictive model constructed represents the Shenandoah River as a series of plug-flow reactors. This type of representation is suitable for flowing waters in which advection dominates, such as the Shenandoah River. A “plug” of a conservative pollutant, such as PCBs, introduced at one end will remain intact as it passes through the reactor. Pollutants are discharged out of the reactor in the same sequence that they enter the reactor. The river was segmented into a series of reactors along the length of the impaired segment (S.F. Shenandoah, N.F. Shenandoah, and Mainstem Shenandoah River), in order to simulate the distribution of PCBs (Figure 5-1). This was necessary to accurately account for the water balance between each segment and the impact of point sources and tributaries on the mainstem of the Shenandoah River. The model represents the segmented systems in one dimension (longitudinal) under a steady-state condition. For TMDL development purposes, the steady-state condition represented the “critical condition.” An additional component was added to the plug-flow model to simulate the burial of PCBs with respect to time in the last segment, located by Millville Dam, WV. This approach allows for a better representation of the flow and physical properties by Millville Dam, WV.

Each of the plug-flow reactors defines a mass balance for PCBs distributed between sediment and water (Figure 5-2). PCBs are partitioned into dissolved and particulate fractions in both the water and sediment layers. Mechanisms such as burial and resuspension act on both components, while diffusion acts selectively on the dissolved fraction. PCBs in the water column and sediment layers are computed as concentration profiles with respect to distance. Using upstream boundary conditions at USGS gauge station 01631000 and tributaries entering the main-stem of Shenandoah River and known values for discrete contributions to the river,the water column concentration of PCBs can be calculated. At each confluence where there is a point source or tributary, a mass balance of the load just upstream and the load from the point source or tributary is performed to determine the change in concentration. This concentration is then used as the initial concentration for the next segment. Governing equation representing the plug-flow reactor model are provided in Appendix F.

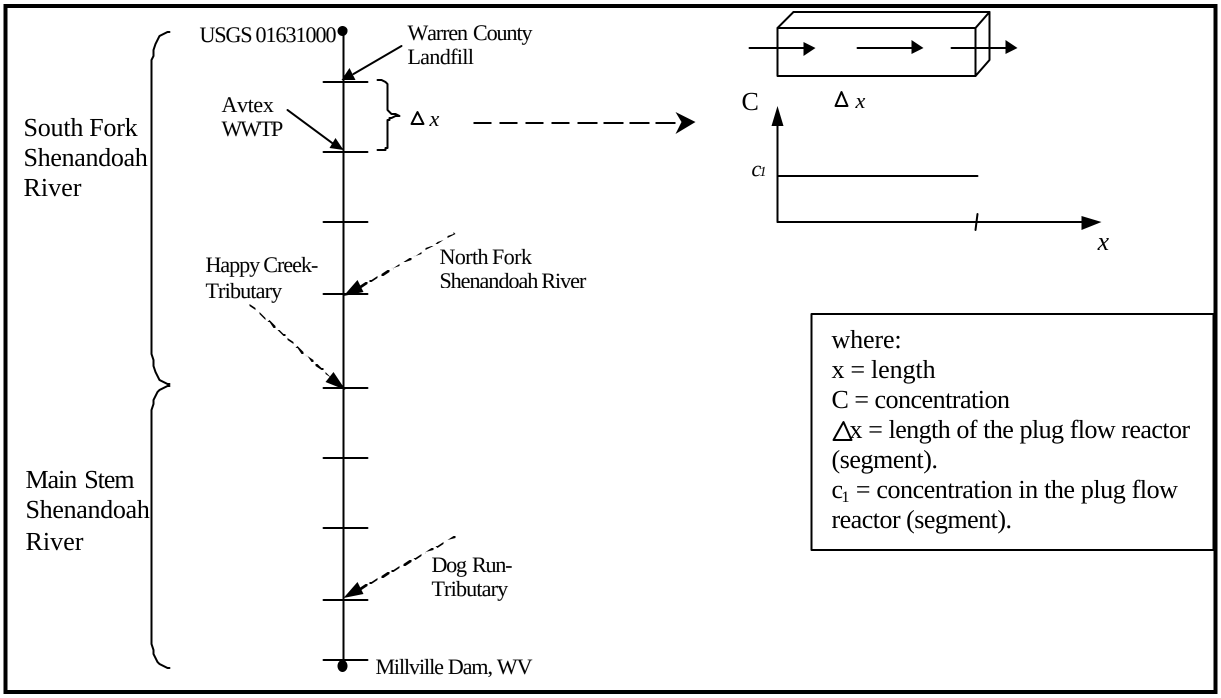

Figure 5-1: Plug-Flow Reactor Representation of the Shenandoah River

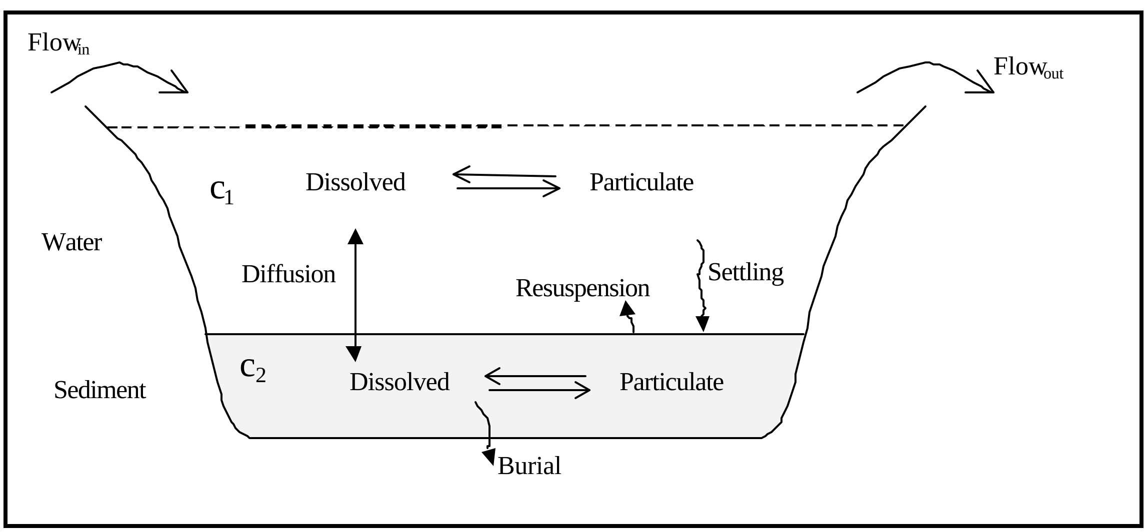

Figure 5-2: Processes and Interactions Represented in the Plug-Flow Reactor

5.1.2. Source Representation

In addition to the major tributaries feeding into the Shenandoah (Dog Run, Happy Creek, and the North Fork Shenandoah River), a number of critical sources identified during monitoring were represented as explicit inputs in the model. The recent sampling event resulted in two water column samples with total PCBs values above the typical detection limit of 0.01 ng/L for EPA analytical Method 1668A (the duplicate for Site #7 has not been treated as an observed concentration for the TMDL since it does not correspond with the original sample). Sites 2 and 3 showed values of 1.68 ng/L and 28.2 ng/L, respectively (Table 4-2). The reported values at other locations were very close to the lab blank, indicating that these values may be minimal (and actually out of the detection range). Based on these results, the two major potential sources of PCBs contamination have been identified as Avtex Fibers, Inc. and the Warren County Landfill. Table 5-1 presents the existing contribution of PCBs from these sources into the S.F. Shenandoah River (based on the sampling event). Avtex facility flow represents the average daily flow reported for the year 2000. The Warren County Landfill flow was estimated during the sampling event.

Table 5-1: Total PCBs Discharge Characteristics in the Shenandoah River

Facility	Total PCBs (ng/L)	Flow (MGD)	Total PCBs Loads (g/yr)
Avtex Fibers, Inc.	28.8*	3.69×10^{-1}	14.2
Warren County Landfill (near S.F. Shenandoah River)	1.49*	9.48×10^{-5}	2.19×10^{-4}

* Based on actual sampling monitoring data.

5.1.3. Analytical Assumptions

Considerations and assumptions used in the modeling effort to support TMDL development include:

- The critical conditions were represented at a steady-state 7Q10 flow condition. The 7Q10 flow condition was selected due to the nature of source contributions to the impairment (direct point source contributions) and it was found to be more critical than the harmonic mean flow.
- Direct discharges of PCBs were assumed constant during the critical condition (based on the recent sampling event).
- Sediment concentrations were defined as a constant fraction of the concentration in the overlaying water.
- Hydrogeometric (i.e. depth, width, velocity) characteristics were assumed constant within each segment.

- Sediments do not move horizontally (no advection).
- PCB decomposition rates were assumed to be zero.
- Volatilization and atmospheric deposition of PCBs were not explicitly modeled.
- Bio-accumulation interactions between organisms were not explicitly modeled (refer to Section 5.4).
- The burial rate was also assumed to be negligible due to the free flowing nature of the river. However, burial rates were considered in the last segment, located by Millville Dam, WV to better represent flow and physical properties by Millville Dam, WV.
- The diffusion rate was calculated using an average molecular weight (>250 gmole) for high molecular weight PCBs (Aroclor 1016, 1242, 1248, 1254 and 1260).
- The fraction of particulate concentration changes with distance, incorporating the TSS results from the sampling event.

The plug-flow model applies analytical solutions to estimate the PCBs concentration profile in the Shenandoah River. PCBs sampling data were used as input to the model rather than for calibration purposes. The plug-flow model used in the TMDL development does not provide a complete representation of sediment transport and dynamics in the stream. Insufficient data are available to fully characterize and simulate sediment dynamics.

As stated earlier, in the plug-flow model, the burial rate is considered to be negligible in the free flowing sections of the Shenandoah River. In the free flowing sections, sediment is being transported downstream to Millville Dam, West Virginia. The dam area was modeled as a lake to take into account deposition and settling with respect to time. Therefore, the free flowing sections are transporting the sediments to Millville Dam where burial (deposition) is taking place. This approach allows for a better representation of the flow and physical properties by Millville Dam, WV.

5.2. TMDL Calculations

The goal of the model application was to determine allowable source contributions which meet the water quality criteria in both Virginia and West Virginia. Boundary conditions and source inputs were adjusted to achieve in-stream water column concentrations of PCBs that meet the TMDL target of 0.044 ng/L in West Virginia and 0.55 ng/L in Virginia.

Because the Virginia water quality criteria for PCBs is based on individual Aroclors, a total PCBs criteria was calculated to allow basis of comparison to the in-stream total PCBs concentration. The Virginia total PCBs water quality criteria of 0.55 ng/L was estimated based on a weight percent of each homolog group with the manufactured Aroclors 1221, 1232, 1016, 1242, 1248,1254, 1260 (GE, 1999). The Aroclors and total PCBs concentration follows a proportional relationship, equating to 0.55 ng/L of total PCBs for each 0.44 ng/L Aroclor.

Figure 5-3 presents the model results for a successful TMDL allocation scenario. In-stream PCBs concentrations (water column) meet water quality criteria in both states. Source allocations for this scenario are presented in Table 5-2 and described in subsequent sections.

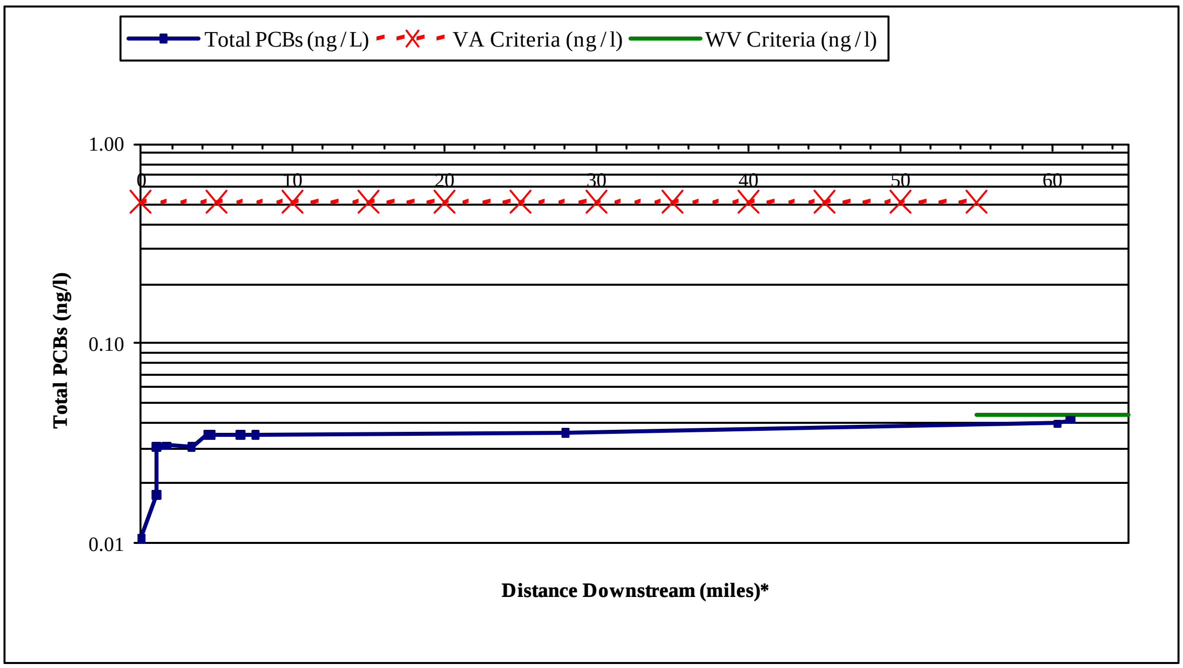

Figure 5-3: Total Modeled PCBs in the Water Column Along the Length of the Shenandoah River

* Zero miles represent the USGS location

Table 5-2: PCBs TMDL Summary[1]

303(d) ID	Impaired Segment	TMDL (g/yr)	WLA (g/yr)	LA (g/yr)	MOS (g/yr)
VAV-B41R VAV-B55R VAV-B57R VAV-B58R	Main Stem and South Fork Shenandoah River	208.23	179.38*	8.04**	20.82

VAA-B51R	North Fork Shenandoah River	0.833	N/A	0.75	0.083
WV-S_1998	Main Stem Shenandoah River	214.7	179.38*	13.85**	21.47

[1] Based on 7Q10 flow condition

***** Avtex Fibers, Inc. was assigned a WLA of 179.38 g/yr

****** Includes allocation to the Warren County Landfill (2.19 x 10^{-4}g/yr)

Note: WLA and LA were assigned based on the assimilative capacity of the Shenandoah River.

5.2.1. Waste Load Allocations (WLAs)

The waste load allocations contain the allowable loadings from existing and/or future point sources. The only known point source facility discharging PCBs into the Shenandoah River, Avtex Fibers, Inc. was modeled as discharging to the stream during a 7Q10 flow at 0.0160 cubic meters per second (based on year 2000 annual flow). The model determined that, based on the assimilative capacity of the Shenandoah River, a waste load allocation of 0.200 ug/L would allow for the attainment of water quality standards in both Virginia and West Virginia. The annual allocation for the Avtex facility is 179.38 g/yr which was determined by multiplying the allowable concentration (200 ug/L) by the annual flow. Method 8082 is the approved sampling methodology for PCBs at Avtex. The detection limit for this method is 0.5 ug/L. The TMDL requests that EPA and FMC conduct an evaluation of PCB analysis and treatment technologies during EPA's 5-year review.

Upon the completion of the remediation project, EPA does not expect the site to be a source of PCBs and has therefore assigned a Load Allocation of zero to the site. However, the WLA will be transferred to the Margin of Safety to account for any uncertainty in the loadings.

5.2.2. Load Allocations (LAs)

The load allocation is the amount of PCBs contributed to the waterbody by nonpoint sources. Nonpoint source contributions of PCBs to the Shenandoah River include runoff from contaminated locations, atmospheric deposition, and historically contaminated sediment within the stream or along the stream banks. Based on the sampling event, outflow from the Warren County Landfill was identified as an explicit nonpoint source of PCBs, and an allocation was defined accordingly. PCBs contributions assigned to all nonpoint sources (including unknown sources) were based on a concentration, at the USGS gauge station, of 0.0106 ng/L.

5.2.3. Margin of Safety

Margin of safety is intended to add a level of conservation to the analytical process to account for any uncertainty. The Margin of safety may be implicit, built into the modeling process, or explicit, taken as a percentage of the wasteload allocation, load allocation or TMDL. A ten percent explicit margin of safety was applied to account for uncertainty in this TMDL.

5.3. Seasonal Variations

A TMDL must consider seasonal variation in the derivation of the allocation. Selection of the critical condition (7Q10 low flow) involved assessment of potential source contributions under a variety of hydrologic regimes (low, mean, and high flow conditions). Based on available monitoring data, Avtex was determined to contribute the greatest load of PCBs to the Shenandoah River. Under low flow conditions, dilution capacity is minimal, and potential contributions from Avtex would have the greatest impact.

5.4. Fish Advisory Criteria and TMDL Endpoint

This section discusses the impact of using the TMDL endpoint of 0.044ng/L for West Virginia and 0.55 ng/L for Virginia versus the fish advisory criteria. While the TMDL endpoint (and thus the source-response linkage) is based on water column criteria, the impact of the TMDL allocations on fish advisories must also be considered.

Fish tissue samples can be converted to water column concentrations using accepted approaches for direct comparison to the water column criteria. EPA's Bioconcentration Factor (BCF) is typically employed in this type of conversion. The BCF for PCBs is 31,200 L/Kg (EPA 440/5-80-068), and represents the accumulation rate of PCBs in fish tissues.

The conversion equation is:

Tissue Level = Water concentration * BCF * unit conversions

Table 5-3 summarizes the advisory criteria and water quality criteria and provides a direct comparison between tissue and water column levels. In order to meet water quality criteria at all locations on the impaired rivers in West Virginia and Virginia, the water column concentration of 0.044 ng/L must be met in West Virginia. Table 5-2 implies that both West Virginia and Virginia water column criteria are more stringent than the FDA or VDH, thus protective of the advisory criteria.

Table 5-3: Total PCBs Water Quality Criteria

Media	Agency	Tissue Level (mg/Kg)	Tissue Level (µg/Kg)	Water Level (ng/L)
Fish	FDA***	***2.0***	2000	64.1
Fish	VDH*	***0.6***	600	19.2
Water	VA	0.014	14	***0.440*****
Water	WV	0.0014	1.4	***0.044***

* Virginia Department of Health.

** Aroclors 1242, 1254, 1221, 1232, 1248, 1260, 1016

*** No advisory level is available for West Virginia; therefore, the state applies the FDA criterion of 2 mg/kg. West Virginia is currently developing a formal advisory update which is planned for July 2001.

Note: The italicized numbers are actual standards. All others are calculations based on a BCF.

Source: VADEQ and WVDEP

Based on Table 5-3, if the water quality criteria is met, than there would be no violations of the fish advisory levels. In other words, the states water quality criteria will be protective of the fish advisories.

A question that remains is whether the PCBs concentrations in the sediment will violate the tissue advisory levels. Using a similar approach, the bioaccumulation factor can be used to estimate the equilibrium concentration of a contaminant in tissues (if sediment in question were the source of PCBs contamination to the organisms). This is the most probable cause of contamination of fish due to PCBs.

The bioaccumulation potential can be calculated relative to the biota-sediment accumulation factor (BSAF), as in the following equation:

$$\textbf{Tissue Level} = (\textbf{Sediment concentration}/f_{oc}) * f_1 * \textbf{BSAF}$$

where

f_{oc}= total organic carbon (TOC) content of sediment expressed as a decimal fraction (typical value of 1%-National Sediment Inventory, 2000)

f_1= organism lipid content (3%- EPA, 1997)

BSAF = biota sediment accumulation factor (1.85 kg sediment organic carbon/kg lipid- EPA-ORD)

To make a relative comparison between sediment concentration and the water quality criteria, the bioaccumulation factor approach was taken. Table 5-4 summarizes the advisory criteria and water quality criteria, and it provides a direct comparison between tissue and sediment levels at Millville Dam, West Virginia (which represents the highest in-stream sediment concentration based on the sampling event).

Table 5-4: Total PCBs in Fish Tissue vs. Sediment

Media	Agency	Tissue Level (mg/Kg)	Tissue Level (µg/Kg)	Sediment Level (mg/Kg)
Fish	FDA	***2.0***	2000	0.360
Fish	VDH*	***0.6***	600	0.108
Sediment	-	0.555	555	***0.1****
Sediment	-	0.0965	96.5	***0.0174*****

* Virginia Department of Health.

** Sediment concentration at Site #5, South Fork Shenandoah,VA (validated data)

*** Sediment concentration at Millville Dam, WV (validated data)

*** No advisory level is available for West Virginia; therefore, the state applies the FDA criterion of 2 mg/kg. West Virginia is currently developing a formal advisory update which is planned for July 2001.

Note: The italicized numbers are actual standards. All others are calculations based on a BSAF.

Source: VADEQ and WVDEP.

The estimated tissue levels listed in Table 5-3, indicate that the highest observed PCBs sediment concentration would not violate the tissue advisory levels.

Section 6: Reasonable Assurances

Reasonable assurance is one of the eight regulatory requirements of a TMDL. The purpose of this Section is to provide a reasonable assurance that the Shenandoah River PCB TMDL targets can be met. Under the Consent Decree between the United States and FMC (effective 21 October 2001), several remedial and removal actions are taking place at Avtex site. One of these actions, plans to shutdown and demolish the Avtex WWTP., which in the future will ensure no discharges of PCBs in the Shenandoah River.

In the plug-flow model, burial rates are considered negligible because of the flowing water characteristics of the Shenandoah River. The main stem of the Shenandoah was divided into segments as illustrated in Figure 5-1. However, the last segment was modified to simulate a lake model, to represent the pool by Millville Dam. In this area, burial was considered and therefore natural attenuation will take place.

Natural attenuation is usually considered to be an appropriate action alternative to ensure that the TMDL targets are met and water quality standards are achieved. Natural attenuation approach involves allowing natural processes such as burial an flushing of sediment during high flow events to decrease the in-stream sediment levels of PCBs. The alternative option, mechanical or vacuum dredging, is not currently justified as a viable approach given the possible habitat destruction, resuspension of PCBs, and high cost involved. It is suggested that in order to assess the progress made towards achieving the Shenandoah River PCB TMDL, monitoring of fish tissue should be continued. It is recommended that an increase in the frequency of monitoring will provide better feedback on maintaining the TMDL goal.

Section 7.0: Public Participation

There were two public meetings held in Front Royal, Virginia to discuss the development of this TMDL. The meetings were held on February 15, 2001 and July 17, 2001 at the Warren County Government Center. The meetings were public noticed in the Virginia Register on January 27, 2001 and June 18, 2001. There was also a 45-day public comment period from July 2, 2001 to August 15, 2001. WVDEP put the TMDL out for public comment on July 2, 2001 in The Journal. A public notice also went out in the Sheperdstown Chronicle and the Jefferson Advocate on July 06, 2001 and July 05, 2001 respectively. WVDEP issued a press release for the first public meeting on February 01, 2001.

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Appendix A.1. USGS Gauge Flow Data

A search of the USGS webpage for historical daily flows found 34 stations with flows. Long term daily flows for the Shenandoah River are available from October 1930 through September 1998. An additional 23 stations with peak flow data were found. The following table shows the sites with peak flow data.

Table A-1-1: USGS Stream Gauges Providing Peak Flow Data

Gauge	Location
01620800	Briery Branch
01621200	War Branch
01621400	Blacks Run
01621450	Blacks Run Trib
01622100	North River Trib
01622300	Buffalo Branch Trib
01622400	Buffalo Branch Trib
01625500	North River @ Port Republic
01627300	South River Trib
01628000	South River @ Port Republic
01628600	Cub Run
01629400	South Fork Trib
01629945	Chub Run
01632300	Long Meadow
01632900	Smith Creek
01632950	Crooked Run
01632970	Crooked Run
01633650	Pughs Run
01633700	Pughs Run
01635200	North Fork Trib
01636000	North Fork @ Riverton
01636200	Shenandoah @ Riverton
01636330	Horsepen Spring

The next table is the gauges with daily flow records and their periods of record. It is significant that the South Fork gauge is in Front Royal near the confluence with the North Fork, while the nearest station on the North Fork is in Strasburg. The increase in drainage area for the North Fork between Strasburg and Front Royal is approximately 33 percent of the total North Fork drainage area at Front Royal. The gauge for the Shenandoah River at Millville is approximately 5 miles from the mouth where it flows into the Potomac River.

Table A-1-2: USGS Stream Gauges Providing Daily Flow Data

Gauge	Name	Drainage (square miles)	Start	Stop
01620500	North River near Stokesville	17.2	10/01/1946	09/30/1999
01621000	Dry River	72.6	08/30/1946	09/30/1948
01621050	Muddy Creek	14.2	04/13/1973	09/30/1999
01621470	Blacks Run	19.4	02/18/1999	09/30/1999
01622000	North River @ Burketown	379	06/01/1926	10/31/1972
			05/23/1975	09/30/1999
01623000	Bell Creek near Staunton	0.61	10/01/1948	09/30/1955
01623500	Bell Creek @ Staunton	3.80	10/01/1948	09/30/1955
01624000	Bell Creek near Franks Mill	9.60	10/01/1948	09/30/1956
01624300	Middle River near Verona	178	10/01/1967	01/09/1987
01624800	Christians Creek	70.1	10/01/1967	10/06/1997
01625000	Middle River @ Grottoes	375	10/01/1927	09/30/1995
01625900	Back Creek	41.2	05/01/1974	09/30/1977
01626000	South River near Waynesboro	127	10/01/1952	09/30/1999
01626500	South River @ Waynesboro	133	10/01/2028	09/30/1952
01626850	South River near Dooms	149	04/23/1974	12/10/1996
01627500	South River @ Harriston	212	02/15/1925	09/30/1951
			10/01/1968	09/30/1999
01628060	White Oak Run	1.94	10/01/1979	09/30/1996
01628150	Deep Run	1.17	10/01/1979	09/30/1982
01628500	South Fork @ Lynnwood	1084	10/01/1930	09/30/1999
01629500	South Fork @ Luray	1377	04/01/1925	09/30/1930
			10/01/1938	09/30/1951
			06/01/1979	09/30/1999
01631000	South Fork @ Front Royal	1642	10/01/1930	09/30/1999
01632000	North Fork @ Cootes Store	210	04/01/1925	09/30/1999
01632082	Linville Creek	45.5	08/09/1985	09/30/1999
01633000	North Fork @ Mount Jackson	506	10/01/1943	09/30/1999
01633500	Stony Creek	79.4	04/01/1947	09/30/1956
01634000	North Fork @ Strasburg	768	04/01/1925	09/30/1999
01634500	Cedar Creek	103	10/01/1937	09/30/1999
01635360	Mill Run	1.17	11/18/1982	08/17/1988
			10/01/1988	05/30/1990
01635365	Shelter Run	0.14	09/02/1982	11/15/1984
			10/01/1985	05/12/1986
			07/15/1986	04/15/1990
01635500	Passage Creek	87.8	04/01/1932	09/30/1999
01636210	Happy Creek	14.0	10/01/1948	10/19/1977
01636451	Long Marsh	16.1	04/21/1988	03/28/1989
			05/03/1989	06/21/1989
01636462	Bullskin Run	22.2	04/21/1988	07/14/1989
01636500	Shenandoah @ Millville	3040	04/01/1895	03/31/1909

Gauge	Name	Drainage (square miles)	Start	Stop
			08/01/1928	09/30/1998

Appendix A.2. Water Quality Data

Water quality data has been obtained from STORET, Virginia DEQ, and the EPA Superfund program. The Virginia DEQ data is included in the STORET data, and is summarized with that data. Current data is for four sample media; clams, sediments, fish, and the water column. The following table provides a broad summary of the data, including the number and percent of data with qualifier flags. The majority of the data with qualifiers are below detection limits or were Not Detected (ND). The clam results show 43% of all samples as remarked while 86% of all fish samples have qualifier flags. The sediment results shows 97% of data is below detection and 93% of water column samples are below detection levels. The available data that is above detection levels is very sparse, both spatially and temporally. A more detailed summary which shows the spatial and temporal availability of data is presented below by source and media.

Table A-2-1: Sources of Water Quality Data

Source	Media	# of Samples	# Remarked	Comments
STORET	Fish	504	423	
STORET	Ambient	188	185	
STORET	Sediment	212	196	Some mud, some dry sediment
Superfund	Clams	53	23	Report both mg/kg and µg/kg
Superfund	Sunfish	295	265	
Superfund	Sediment	281	281	All not detected
Superfund	Ambient	180	156	All entries not detected

Water Quality Analysis by Source and Media

The following data summaries are divided by source/agency and sample media (clams, fish, sediment, water). If several media were collected at a station, the station will appear in the table of results for each media. The detected compounds are predominantly PCB-1260 and Total PCBs, with the 2 values very similar or equal. PCB-1254 is also detected in some samples, primarily fish tissue. Unless otherwise stated, the sample counts are for all PCB parameters.

Much of the data has a data qualifier flag associated with each reading. The qualifier definitions for STORET and the Superfund program are generally similar. The following table summarizes the qualifiers in the Shenandoah data and how various qualifiers were used in this report. The U qualifier was used for all data with a value of 0.

Table A-2-2: Water Quality Data Qualifiers

Superfund	STORET	Report	Definition
J	J	J	Estimated values
K	K	K	Below detection level
	M	U	Present, but not quantified
R		R	Rejected for gross QC problems
U	U	U	Not detected (ND)
UJ		U	Estimated value for ND
UL		U	ND, greater than value shown
W		W	Weathered for PCB analysis
WJ		W	Estimated value, weathered for PCB analysis

Superfund Data

Sample Type: Clams

Date: 05/13/97

Table A-2-3: Superfund Data for Clams

Units	Count	Minimum	Maximum	Comments
mg/kg	30	0.320	16	
µg/kg	23	100	16000	All flagged W. Detection limits between 68 and 83.

Converting the µg/kg detection limits to mg/kg gives a range of 0.068 to 0.083 mg/kg respectively. The range of results for the µg/kg data is 0.1 mg/kg to 16 mg/kg. If the W flag does not require special data interpretation, the two sets of results could be combined.

Sample Type: Fish

Date: 05/13/97

Table A-2-4: Superfund Data for Fish

Units	Count	Minimum	Maximum	Comments
mg/kg	25	2	9.3	
mg/kg	164	ND	ND	Detection limit of 1
µg/kg	5	97	500	
µg/kg	6	21	48	Estimated values
µg/kg	28	ND	ND	Detection of 110 to 1000
µg/kg	67	37	9600	Detection of 67 to 130

Sample Type: Sediment

Dates: 09/23/93, 05/13/97

Table A-2-5: Superfund Data for Sediment

Units	Count	Minimum	Maximum	Comments
mg/kg	3	ND	ND	All U, detection of 2 or 2.9
μg/kg	278	ND	ND	All U, detection between 30 and 760

Sample Type: Water

Dates: 09/23/93, 05/13/97

Table A-2-6: Superfund Data for Water

Units	Count	Minimum	Maximum	Comments
mg/L	25	ND	ND	All U, detection of 0.0001
μg/L	155	ND	ND	All U, detection of 0.3 or 0.5

The 0.3 μg/L detection level is 680 times greater than the Virginia standard and 6800 times greater than the West Virginia standard.

STORET Data

USEPA Region 3

Sample Type: Water

Table A-2-7: STORET Data for Water

Station	Date	Count	Minimum	Maximum	Comments
Front Royal	01/10/79	7	ND	ND	One sample, 7 parameters, all ND
Waynesboro	05/01/79	7	ND	ND	One sample, 7 parameters, all ND

The 0.1 μg/L detection limit used is 230 times greater than the Virginia standard and 2300 times greater than the West Virginia standard.

USGS Data

Table A-2-8: USGS Water Quality Gauge Stations

AGENCY	STATION	LOCATION
112WRD	01621050	MUDDY CREEK AT MOUNT CLINTON, VA
112WRD	01628250	SOUTH FORK SHENANDOAH RIVER AT LYNNWOOD, VA
112WRD	01629050	S F SHENANDOAH RIVER AT ELKTON, VA
112WRD	01629500	S F SHENANDOAH RIVER NEAR LURAY, VA
112WRD	01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA
112WRD	01633000	N F SHENANDOAH RIVER AT MOUNT JACKSON, VA
112WRD	01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA
112WRD	01636290	SHENANDOAH RIVER NEAR MILLWOOD, VA
112WRD	01636451	NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV
112WRD	01636462	BULLSKIN RUN AT KABLETOWN,WV
112WRD	01636500	SHENANDOAH R AT MILLVILLE, WV
112WRD	391200077520301	03722 D N HOOVER
112WRD	391413077572301	37252 HEAD SPRING
112WRD	391655077493801	CATTAIL SPRING 88A
112WRD	391805077550701	ALDRIDGE SPRING @ ALDRIDGE, WV
112WRD	391840077504001	037109 FLOWING SPRING (KANE)

Sample Type: Fish

Table A-2-9: USGS Data for Fish

Station	Date	Count	Value	Detection Limits
01621050	07/26/95	1	ND	50 µg/kg

Sample Type: Sediment

Table: A-2-10: USGS Data for Sediment

Station	Location	Date	Value (µg/kg)	Flag
01629050	S F SHENANDOAH RIVER AT ELKTON, VA	05/16/72	80	
01629050	S F SHENANDOAH RIVER AT ELKTON, VA	08/31/76	0	
01629500	S F SHENANDOAH RIVER NEAR LURAY, VA	05/16/72	5	
01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	05/16/72	30	
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	05/16/72	0	
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	08/31/76	0	
01636290	SHENANDOAH RIVER NEAR MILLWOOD, VA	05/16/72	0	
01636290	SHENANDOAH RIVER NEAR MILLWOOD, VA	08/31/76	0	
01636500	SHENANDOAH R AT MILLVILLE, WV	05/17/72	5	BD
01636500	SHENANDOAH R AT MILLVILLE, WV	08/31/76	0	

All 10 samples were “wet mud”. Three samples were above detection levels on 05/16/72. One detection limit of 5 µg/kg was listed for 1972. The three detected samples were on the south fork at Elkton (80 µg/kg), Front Royal (30 µg/kg), and Luray (5 µg/kg). The Millville sample for that date was below detection.

Sample Type: Water

Table A-2-11: USGS Data for Water

Station	Location	Date	Value (µg/L)	Flag
01628250	SOUTH FORK SHENANDOAH RIVER AT LYNNWOOD, VA	06/19/73	0.0	
01628250	SOUTH FORK SHENANDOAH RIVER AT LYNNWOOD, VA	10/25/72	0.0	
01628250	SOUTH FORK SHENANDOAH RIVER AT LYNNWOOD, VA	12/13/72	0.0	
01629050	S F SHENANDOAH RIVER AT ELKTON, VA	08/31/76	0.0	
01633000	N F SHENANDOAH RIVER AT MOUNT JACKSON, VA	02/21/80	0.0	U
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	08/31/76	0.0	
01636290	SHENANDOAH RIVER NEAR MILLWOOD, VA	06/19/73	0.0	
01636290	SHENANDOAH RIVER NEAR MILLWOOD, VA	08/31/76	0.0	
01636290	SHENANDOAH RIVER NEAR MILLWOOD, VA	10/25/72	0.0	U
01636290	SHENANDOAH RIVER NEAR MILLWOOD, VA	12/14/72	0.0	
01636451	NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	03/28/89	0.1	BD
01636451	NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	06/21/89	0.1	K
01636462	BULLSKIN RUN AT KABLETOWN,WV	06/21/89	0.1	K
01636500	SHENANDOAH R AT MILLVILLE, WV	08/31/76	0.0	
391200077520301	03722 D N HOOVER	07/26/88	0.1	K
391413077572301	37252 HEAD SPRING	03/29/89	0.1	K

Station	Location	Date	Value (µg/L)	Flag
391413077572301	37252 HEAD SPRING	06/20/89	0.1	K
391655077493801	CATTAIL SPRING 88A	07/27/88	0.1	K
391805077550701	ALDRIDGE SPRING @ ALDRIDGE, WV	06/20/89	0.1	K
391805077550701	ALDRIDGE SPRING @ ALDRIDGE, WV	09/27/88	0.1	K
391840077504001	037109 FLOWING SPRING (KANE)	07/25/88	0.1	K

All 21 samples were reported as 0 or below a detection limit of 0.1 µg/L. The detection limit is roughly 230 times greater than the Virginia standard and 2300 times greater then the West Virginia standard.

Army Corps of Engineers, Huntington Division

The Army Corp of Engineers data was collected on Evitts Run, a small trib that joins the Shenandoah near Mechanicstown, WV.

Sediments

Samples were tested for 7 Aroclors on each day. All data were below detection levels of 1.6 to 8.3 µg/kg. The detection limits were not uniform for any date, station, or Aroclor parameter.

Table A-2-12: USACE Aroclor Data for Sediments

Site	Date	Count	Minimum	Maximum	Comment
1AMEW0002	10/07/93	7	1.8	5.0	ND
1AMEW0002	07/07/94	7	2.1	6.0	ND
1AMEW0003	10/07/93	7	1.9	5.4	ND
1AMEW0003	07/07/94	7	2.8	8.0	ND
1AMEW0004	10/08/93	7	1.6	4.5	ND
1AMEW0004	07/07/94	7	2.4	6.8	ND
1AMEW0005	10/08/93	7	1.7	4.9	ND
1AMEW0005	07/07/94	7	3.0	8.3	ND

Note: ND = not detectable

Water

Samples at 6 stations were tested for 6 Aroclors in October. One extra Aroclor was tested for at station 1AMEW0007 in December. All samples are below detection levels of 0.023 to 0.065 µg/L. These detection limits are 50 to 150 times greater than the Virginia standard and 500 to 1500 times greater than the water quality standard for West Virginia.

Table A-2-13: USACE Aroclor Data for Water Column

Site	Date	Count	Minimum	Maximum	Comments
1AMEW0001	10/07/93	6	0.023	0.065	BD

Site	Date	Count	Minimum	Maximum	Comments
1AMEW0002	10/07/93	6	0.023	0.065	BD
1AMEW0003	10/07/93	6	0.023	0.065	BD
1AMEW0004	10/07/93	6	0.023	0.065	BD
1AMEW0005	10/07/93	6	0.023	0.065	BD
1AMEW0007	12/17/93	7	0.023	0.065	BD

West Virginia DNR Sediment and Tissue

Sample Type: Fish Tissue

Table A-2-14: WVDNR Data for Fish Tissue

Site	Date	Count	Minimum	Maximum	Comments
Meyerstown	10/15/81	4	0.05	0.05	BD
Meyerstown	10/17/83	4	0.00	0.25	2 entries as (0)
Meyerstown	09/27/84	5	0.00	0.13	3 entries as (0)
Meyerstown	10/11/89	48	0.00	11.80	6 samples, 6 of 8 tests (0)
Meyerstown	10/28/93	8	0.24	11.74	4 samples for total and 1260
Millville	09/01/78	16	0.00	0.50	2 samples, 5 of 8 tests (0)
Millville	10/11/89	48	0.00	4.30	6 samples, 6 of 8 tests (0)
Millville	10/28/93	12	0.11	4.89	6 samples for total and 1260

Data Summary:

For Meyerstown

- 41 of 69 samples reported as 0
- 2 samples for PCB-1254 on 10/15/81 reported as µg/kg were below 0.05 detection limit
- 2 samples for PCB-1260 on 10/15/81 reported as mg/kg were below 0.05 detection limit
- 24 samples reported as fish tissue wet weight in mg/kg
  - Values for the 24 samples were between 0.13 and 11.8mg/kg.
  - The 9/27/84, 10/11/89, and 10/28/93 samples showed a wide variation in concentration.
  - The samples above detection were tested for total PCBs and aroclor 1260.
  - The PCB-1260 and total PCB values were very similar for a given date and time.

For Millville

- 46 of 76 samples reported as 0

- 1 sample for PCB-1254 on 09/01/78 reported as µg/kg was below 0.50 detection limit
- 1 sample for PCB-1260 on 09/01/78 reported as mg/kg was below 0.05 detection limit
- 28 samples reported as fish tissue wet weight in mg/kg
  - Values for the 28 samples were between 0.11 to 4.89 mg/kg.
  - The 9/27/84, 10/11/89, and 10/28/93 samples showed a wide variation in concentration.
  - The samples above detection were tested for total PCBs and aroclor 1260.
  - The PCB-1260 and total PCB values were very similar for a given date and time.

Virginia State Water Control Board (SWCB)

Sample Type: Water

Water samples were collected on 28 dates. The values shown are the actual values or range of values for that site and day. If one value is listed for multiple samples, all samples were reported with that value, usually because of detection limits.

- 58 of 102 samples were reported as 0
- 6 samples taken on 07/13/90 at one station were not detected at 0.02 µg/L
- 36 samples were not detected at 0.10 µg/L detection level
- The 2 samples with reported values were collected 05/02/71 and 06/06/71.

Table A-2-15: SWCB PCB Data for Water

Station	Location	Date	Count	Value (µg/L)	Flag
1BCDR013.29	ROUTE 628 BRIDGE	08/21/79	1	0.00	
1BCDR013.29	ROUTE 628 BRIDGE	07/21/80	1	0.00	
1BCDR013.29	ROUTE 628 BRIDGE	05/29/85	6	0.10	K
1BCNG003.33	LAKE SHENANDOAH - LAKE CENTER - ALBERMARLE CO.	08/01/89	12	0.10	K
1BCRO000.43	RIVERTON CORP. BRIDGE	07/21/80	1	0.00	
1BCST012.32	ROUTE 794 BRIDGE (AUGUSTA COUNTY)	08/15/79	1	0.00	
1BCST012.32	ROUTE 794 BRIDGE (AUGUSTA COUNTY)	07/10/80	1	0.00	
1BCST012.55	ROUTE 794 BRIDGE	08/15/79	1	0.00	
1BCST012.55	ROUTE 794 BRIDGE	07/10/80	1	0.00	
1BDRI005.55	LAKE ARROWHEAD - STATION 100' FROM DAME PAGE CO.	07/31/90	6	0.02	K
1BHKS000.96	ROUTE 648 BRIDGE BELOW LURAY	08/20/79	1	0.00	
1BHKS000.96	ROUTE 648 BRIDGE BELOW LURAY	07/08/80	1	0.00	
1BHKS006.23	ROUTE 675 BRIDGE IN LURAY	06/06/71	1	0.16	

Station	Location	Date	Count	Value (µg/L)	Flag
1BLEW002.91	APPROX. 0.3 MILES BELOW RT. 275 BRIDGE	07/10/80	1	0.00	
1BLNV000.21	DOWNSTREAM OF RT. 257 BRIDGE	04/23/78	1	0.00	
1BLNV000.21	DOWNSTREAM OF RT. 257 BRIDGE	08/06/79	1	0.00	
1BLNV000.21	DOWNSTREAM OF RT. 257 BRIDGE	07/01/80	1	0.00	
1BMDL001.83	ROUTE 769 BRIDGE	08/15/79	1	0.00	
1BMDL001.83	ROUTE 769 BRIDGE	07/10/80	1	0.00	
1BMDL036.08	ROUTE 742 BRIDGE	08/15/79	1	0.00	
1BMDL036.08	ROUTE 742 BRIDGE	07/10/80	1	0.00	
1BNFS000.57	APPROX. 0.1 MILE BELOW RT. 340/522 BRIDGE	08/21/79	1	0.00	
1BNFS000.57	APPROX. 0.1 MILE BELOW RT. 340/522 BRIDGE	07/21/80	1	0.00	
1BNFS000.57	APPROX. 0.1 MILE BELOW RT. 340/522 BRIDGE	05/29/85	6	0.10	K
1BNFS010.34	RT. 55 BRIDGE WARREN/SHENANDOAH COUNTY	08/21/79	1	0.00	
1BNFS010.34	RT. 55 BRIDGE WARREN/SHENANDOAH COUNTY	07/21/80	1	0.00	
1BNFS070.67	ROUTE 698 BRIDGE	04/23/79	1	0.00	
1BNFS070.67	ROUTE 698 BRIDGE	08/06/79	1	0.00	
1BNFS070.67	ROUTE 698 BRIDGE	07/01/80	1	0.00	
1BNFS081.42	RT. 617/953 BRIDGE, W OF NEW MARKET	04/23/79	1	0.00	
1BNFS081.42	RT. 617/953 BRIDGE, W OF NEW MARKET	08/06/79	1	0.00	
1BNFS081.42	RT. 617/953 BRIDGE, W OF NEW MARKET	07/01/80	1	0.00	
1BNFS093.53	ROUTE 259 BRIDGE	04/23/79	1	0.00	
1BNFS093.53	ROUTE 259 BRIDGE	08/06/79	1	0.00	
1BNFS093.53	ROUTE 259 BRIDGE	07/01/80	1	0.00	
1BNTH014.08	RT. 693 AT QUARRY DOWNSTREAM FROM GAGING STATION	09/27/79	1	0.00	
1BNTH014.08	RT. 693 AT QUARRY DOWNSTREAM FROM GAGING STATION	07/10/80	1	0.00	
1BNTH045.36	STATION A1 - NEAR THE DAM - AUGUSTA COUNTY	06/21/88	6	0.10	K
1BPSG001.36	RT. 55 BRIDGE	08/21/79	1	0.00	
1BPSG001.36	RT. 55 BRIDGE	07/21/80	1	0.00	
1BSHN022.63	RT. 7 BRIDGE, CASTLEMANS FERRY BRIDGE	08/30/79	1	0.00	
1BSHN022.63	RT. 7 BRIDGE, CASTLEMANS FERRY BRIDGE	07/14/80	1	0.00	
1BSHN038.27	RT. 50 BRIDGE	05/02/71	1	0.10	
1BSKD003.18	STATION A1 - NEAR THE DAM - ROCKINGHAM COUNTY	06/28/88	6	0.10	K
1BSMT004.60	RT. 620 BRIDGE	04/23/79	1	0.00	
1BSMT004.60	RT. 620 BRIDGE	08/06/79	1	0.00	
1BSMT004.60	RT. 620 BRIDGE	07/01/80	1	0.00	
1BSSF000.58	APPROX. 0.4 MILE BELOW RT340/522 BRIDGE	08/20/79	1	0.00	
1BSSF000.58	APPROX. 0.4 MILE BELOW RT340/522 BRIDGE	07/08/80	1	0.00	
1BSSF003.56	RT. 619 BRIDGE AT GAGING STATION	08/20/79	1	0.00	

Station	Location	Date	Count	Value (µg/L)	Flag
1BSSF003.56	RT. 619 BRIDGE AT GAGING STATION	07/08/80	1	0.00	
1BSSF054.20	RT. 211 BRIDGE, E OF NEW MARKET	08/20/79	1	0.00	
1BSSF054.20	RT. 211 BRIDGE, E OF NEW MARKET	07/08/80	1	0.00	
1BSSF100.10	RT. 708 BRIDGE	08/20/79	1	0.00	
1BSSF100.10	RT. 708 BRIDGE	07/08/80	1	0.00	
1BSTH007.80	RT. 778 AT HARRISONBURG	08/15/79	1	0.00	
1BSTH007.80	RT. 778 AT HARRISONBURG	07/10/80	1	0.00	
1BSTH027.85	ROUTE 664 BRIDGE - CITY OF WAYNESBORO	08/15/79	1	0.00	
1BSTH027.85	ROUTE 664 BRIDGE - CITY OF WAYNESBORO	07/10/80	1	0.00	
1BSTY001.22	RT. 11 BRIDGE	04/23/78	1	0.00	
1BSTY001.22	RT. 11 BRIDGE	08/06/79	1	0.00	
1BSTY001.22	RT. 11 BRIDGE	07/01/80	1	0.00	
2-HRD011.57	RT. 637 BRIDGE	04/17/79	1	0.00	
2-HRD011.57	RT. 637 BRIDGE	08/16/79	1	0.00	
2-HRD011.57	RT. 637 BRIDGE	07/16/80	1	0.00	
2-HRD011.57	RT. 637 BRIDGE	07/23/80	1	0.00	

Sample Type: Fish Tissue

The Virginia State Water Control Board fish tissue results (mg/kg) show

- 284 of 358 results reported as not detected (U)
- 45 samples below detection levels
- 29 samples above detection levels
- Most samples were tested for multiple parameters, with a few results for PCB-1254 and most results for Total PCB and PCB-1260.

Table A-2-16: SWCB PCB Data for Fish Tissue

Site	Date	Count	Minimum	Maximum	Comments
1BCDR013.29	07/24/79	2	1.00	1.00	All U
1BCDR013.29	08/04/81	2	0.50	0.50	All U
1BCDR013.29	07/27/83	3	0.01	2.30	One of 3 samples U
1BCDR013.29	08/13/85	3	0.01	0.01	All U
1BCDR013.29	07/16/86	9	1.00	1.00	All K
1BNFS000.57	08/18/88	3	1.00	1.00	All K
1BNFS000.69	07/26/79	2	1.00	1.00	All U
1BNFS000.69	07/28/83	3	1.00	1.00	All U
1BNFS000.69	08/14/85	3	1.00	1.00	All U
1BNFS000.69	08/18/88	9	0.10	4.20	7 of 9 K, one of 3 samples PCB-1260 same as total

Site	Date	Count	Minimum	Maximum	Comments
1BNFS000.69	09/12/90	9	1.00	1.00	All U
1BNFS005.33	09/12/90	25	1.00	1.00	All U
1BNFS037.89	09/13/90	27	1.00	1.00	All U
1BSHN022.63	07/16/87	9	1.00	5.20	3 samples, 3 tests, PCB-1260 same as total, PCB-1254 was ND
1BSHN022.63	06/05/90	27	0.50	4.40	All U
1BSHN022.63	07/16/92	26	1.00	1.00	All U
1BSHN038.48	06/05/90	27	0.50	7.50	All U
1BSHN048.00	06/06/90	27	0.50	9.70	All U
1BSHN052.03	07/14/92	18	1.00	1.00	All U
1BSHN053.02	06/06/90	27	0.50	18.00	All U
1BSSF000.19	08/17/88	3	2.40	12.00	1 sample 3 tests
1BSSF000.58	07/26/79	4	1.00	1.00	All U
1BSSF000.58	07/28/83	3	0.01	0.01	All U
1BSSF000.58	08/14/85	3	0.01	0.01	All U
1BSSF000.58	08/16/88	3	3.00	21.00	1 sample 3 tests
1BSSF000.58	08/17/88	9	1.00	110.00	3 samples, 3 tests, PCB-1254 ND 2 of 3
1BSSF000.58	06/06/90	27	0.50	50.00	3 samples, 9 tests, 7 tests all ND
1BSSF000.58	07/14/92	18	1.00	1.00	All U
1BSSF003.50	07/16/92	27	1.00	1.00	All U

The 13 stations for the fish tissue data are as follows:

Table A-2-17: SWCB Stations Recording Fish Tissue Data

Agency	Station	Location
21VASWCB	1BCDR013.29	ROUTE 628 BRIDGE
21VASWCB	1BNFS000.57	APPROX. 0.1 MILE BELOW RT. 340/522 BRIDGE
21VASWCB	1BNFS000.69	UPSTREAM FROM DAM
21VASWCB	1BNFS005.33	AT CONFLUENCE OF PASSAGE CREEK
21VASWCB	1BNFS037.89	ROUTE 663 BRIDGE
21VASWCB	1BSHN022.63	RT. 7 BRIDGE, CASTLEMANS FERRY BRIDGE
21VASWCB	1BSHN038.48	AT RT. 17.50 BRIDGE
21VASWCB	1BSHN048.00	RT. 624 BRIDGE
21VASWCB	1BSHN052.03	POWER POOL (WARREN CO)
21VASWCB	1BSHN053.02	DOWNSTREAM OF FRONT ROYAL COUNTRY CLUB
21VASWCB	1BSSF000.19	APPROX. 0.4 MILE BELOW RT340/522 BRIDGE
21VASWCB	1BSSF000.58	APPROX. 0.4 MILE BELOW RT340/522 BRIDGE
21VASWCB	1BSSF003.50	DGIF BOAT LAUNCH LURAY AVE - WARREN COUNTY

Sample Type: Sediment

- Sediments were collected on 45 dates and at 90 stations
- The combination results in 143 station/date combinations
- 133 of 146 samples were below detection or reported as 0
- 6 of the 13 samples above the detection limits were reported at 500 μg/kg
- 7 of the 13 samples above the detection limits were reported at 1000 μg/kg
- Detection limits for all samples ranged between 20 μg/kg in 1996 to 1000 μg/kg in 1988
- The majority of the samples above detection limits were collected in July 1991

The table below shows the data for the stations where samples above the detection limit were found.

Table A-2-18: SWCB Stations With Samples Above Detection Limit

Station	Location	Date	Value (μg/kg)	Flag
1BCNG003.33	LAKE SHENANDOAH - LAKE CENTER - ALBERMARLE CO.	08/01/89	1000.0	K
1BCNG003.33	LAKE SHENANDOAH - LAKE CENTER - ALBERMARLE CO.	08/01/89	1000.00	
1BCRO000.43	RIVERTON CORP. BRIDGE	07/23/91	500.00	
1BCRO000.43	RIVERTON CORP. BRIDGE	07/25/96	30.00	U
1BCST012.32	ROUTE 794 BRIDGE (AUGUSTA COUNTY)	07/01/91	1000.00	
1BDRI005.55	LAKE ARROWHEAD - STATION 100' FROM DAME PAGE CO.	07/31/90	1000.00	
1BDUR003.36	ROUTE 752 BRIDGE	07/02/91	1000.00	
1BMDD000.40	ROUTE 737 BRIDGE	07/02/91	1000.00	
1BMDD000.40	ROUTE 737 BRIDGE	06/18/96	30.00	U
1BMDD005.15	ROUTE 875 BRIDGE	07/02/91	1000.00	
1BNFS000.57	APPROX. 0.1 MILE BELOW RT. 340/522 BRIDGE	07/23/91	500.00	
1BNFS000.57	APPROX. 0.1 MILE BELOW RT. 340/522 BRIDGE	07/24/96	30.00	U
1BSHN022.63	RT. 7 BRIDGE, CASTLEMANS FERRY BRIDGE	06/05/90	180.00	U
1BSHN022.63	RT. 7 BRIDGE, CASTLEMANS FERRY BRIDGE	07/23/91	500.00	
1BSHN022.63	RT. 7 BRIDGE, CASTLEMANS FERRY BRIDGE	07/16/92	500.00	U
1BSHN022.63	RT. 7 BRIDGE, CASTLEMANS FERRY BRIDGE	07/24/96	30.00	U
1BSHN048.00	RT. 624 BRIDGE	06/06/90	250.00	U
1BSHN048.00	RT. 624 BRIDGE	07/23/91	500.00	
1BSHN048.00	RT. 624 BRIDGE	07/24/96	30.00	U
1BSSF000.19	APPROX. 0.4 MILE BELOW RT340/522 BRIDGE	07/23/91	500.00	
1BSSF000.19	APPROX. 0.4 MILE BELOW RT340/522 BRIDGE	07/24/96	30.00	U
1BSTH027.85	ROUTE 664 BRIDGE - CITY OF WAYNESBORO	07/01/91	1000.00	
1BSTH027.85	ROUTE 664 BRIDGE - CITY OF WAYNESBORO	07/22/96	20.00	U
2-HRD011.57	RT. 637 BRIDGE	07/24/91	500.00	
2-HRD011.57	RT. 637 BRIDGE	08/19/96	30.00	U

Appendix B.1. Resource Conservation and Recovery Act (RCRA) Site Information

B.1.1. Wilson Jones

EPA records for the Wilson Jones site are dated September 1999 and indicate Environmental Indicator inspections of this facility are being planned to determine if RCRA Corrective Action is necessary. No telephone listing was located. An address search found Carrington Homes at the listed site. If PCBs had been detected, property transfer would have been prohibited. The Wilson Jones site is therefore assumed not to be a source of PCBs.

B.1.2. General Electric Company

The General Electric Company produces incandescent light bulbs at their Winchester plant. The site is 3 miles south of Winchester and is situated on 125 acres. The light bulb components are manufactured at other facilities and assembled in Winchester. RCRA evaluated due to two former underground fuel tanks and a hazardous waste storage pad. The concrete pad used for storing hazardous wastes was cleaned in 1989. Soil samples show no contamination, and VADEQ provided approval of the "clean closure" certification in 1998. "Clean closure" is used to define the process of removing all waste from a hazardous waste site. The underground tanks have been removed, the soils tested, and "clean closure" certified by VADEQ. The General Electric Winchester plant is therefore not assumed to be a source of PCBs.

B.1.3. Merck & Company, Inc.

Merck & Company, Inc. maintains a facility in northwestern Virginia, approximately 2 miles southwest of Elkton. The plant is southeast of the South Fork of the Shenandoah River. It has been in operation since 1941 and includes a pharmaceutical laboratory and manufacturing facility for human and animal health care products. There is an onsite sanitary landfill which occupies 7 acres in the northeastern corner of the property. Prior to 1980, various production wastes, including organic and inorganic chemicals, were included in the waste stream. This had resulted in groundwater contamination by acetone, carbon tetrachloride, toluene, vinyl chloride, naphthalene, and phenols. No contamination due to PCBs was identified. The Merck facility is assumed not to be a source of PCBs.

B.1.4. Genicom

Genicom Corporation maintains a facility in Waynesboro on a 115 acre parcel. Prior to 1954, the facility was an airfield. From 1954 to 1983, General Electric operated an electro-mechanical equipment manufacturing plant at the site. In 1983, Genicom bought the facility and began to manufacture computer printers and related equipment. The primary waste streams were inorganic wastes and waste solvents from painting and etching. Much of the contamination is believed to originate with the GE operations that predate the RCRA requirement of the 1980's. The contaminant of concern is a trichloroethylene or TCE, which has created a groundwater contamination plume extending off the property. No contamination due to PCBs was identified. The Genicom facility is therefore assumed not to be a source of PCBs.

B.1.5. Wagner Electric

Wagner Electric, which is listed as Federal Mogul Friction Products on the Region 3 RCRIS system, is involved in the manufacturing of automotive products including brake linings. No direct discharges to the surface water exist, but there are releases to the sewer, air, and land. The Envirofacts report for the facility lists asbestos, metals, and solvents as the waste streams. The solvents listed were methyl ethyl ketone, phenol, and toluene. Based on this information, there is no reason to include this facility in the list of possible PCB sources in the Shenandoah watershed.

B.1.6. DuPont De Nemours

DuPont De Nemours maintains a facility in Waynesboro that produces manmade organic fabrics, synthetic resins, and plastics materials. The facility began manufacturing acetate yarn in 1929 and continued until 1990. Current production products include Lycra and BCF Nylon. The 177 acre site is in the southeastern portion of Waynesboro, in an industrial zone. There are approximately twenty Solid Waste Management Units on the site. The Envirofacts reports available on the Web include the NPDES monitoring requirements. The monitoring requirements include numerous organic chemicals. The RCRA website lists volatile organic compounds, semi-volatile organic compounds, and mercury as the main pollutants of concern for the site. Based on this information, there is no reason to include the DuPont facility as a source of PCBs.

Appendix B.2. CERCLA Sites Information

B.2.1. BFI Kwik Klean Sanitary Landfill

The BFI Kwik Klean sanitary landfill is an inactive 15-acre landfill located in Berryville, Virginia. The site is located on Route 612 off of Route 7 and was active from 1969 - 1981. The site received both residential and industrial wastes. It was cited in the past for discharging leachate into local surface waters. The facility was partially capped upon closure. Soils, streams, discharge springs and seeps were sampled as part of the 1985 Site Inspection.

Waste types received at the landfill from 1969 through 1972 are unknown and records do not exist. BFI purchased the facility in 1972, and from that point on, records were maintained. From 1972 - 1980, 70 percent of the waste received was from residential sources (Warren and Frederick Counties). The remainder of the waste consisted of commercial wastes from Capitol Records and Rubber Maid, asbestos from Abex Corp. (brake manufacturer), carbon disulfide (a byproduct generated by Visco during rayon production), and municipal sewage sludge from Seneca sludge.

The site operated under State Landfill permit #197. VA SWCB issued a no discharge certificate (IW-ND-537) in 1976, because of leachate being discharged to an unnamed tributary on site. The certificate was revoked in 1981 when VA SWCB sampling revealed the problem was addressed.

A stream which originates onsite from a spring, flows through the site, discharging into a sediment pond. The pond discharges to the Shenandoah River. Sediment and aqueous samples were taken from the spring, the leachate, the culvert into the pond, and the culvert outlet for the pond. No PCBs were detected in these samples. Hexanone, 4-methyl-2-petanone, isophorone, acetone, Trichloroethylene (TCE), 2-methylphenol, 2,4-dimethylphenol, benzyl alcohol, ethylbenzene, toluene, carbon disulfide were all detected at levels below a health concern. No metals were detected at levels that would pose a health concern. It was deemed that no further action was warranted (NFRAP).

B.2.2. Stauffer Chemical Company

The Stauffer Chemical Company site is a former carbon disulfide manufacturing plant, approximately 26 acres in size, located in Bentonville, Warren County, Virginia. The site is located at the end of Bubb Lane approximately 0.2 miles southeast of the intersection of Route 340 and 613. It consists of a 13-acre storage and production area and a 13-acre brick dump and acid pond. The acid pond was constructed after production ceased and received runoff from the brick dump and production area. Also there are two 5,000 square foot carbon disulfide pits.

The facility operated from 1945-1957 as a carbon disulfide manufacturing plant. It produced 40 tons per day of carbon disulfide and 20 tons per day of sodium hydrosulfide (by-product). Raw materials included dry sulfur, hardwood charcoal or oil coke, sodium hydroxide, and coal.

The facility was first investigated by VA SWCB and EPA in 1982. VOCs were detected in an onsite well (later attributed to a gas station), samples from the acid pond showed high levels of metals (most notably chromium), a sump in the rear of the building detected carbon disulfide. An onsite spring also had elevated metals as well. A 1983 SWCB report indicated runoff from the site was impacting sensitive organisms in Flint Run Creek, a tributary to the South Fork of the Shenandoah River. In a 1984 EPA report, a sediment sample from a concrete slump contained PCBs (Aroclor 1260) at 220 ug/Kg (ppb) and high metals. High metals were also detected in two springs on the property. The toxicological report from the 1986 EPA Site Inspection indicated the high levels of chromium, zinc, iron, aluminum, copper, and nickel from two onsite ponds, exceeded protective criteria for aquatic life. Chromium was found at concentrations at which it would be corrosive to skin. Chromium, aluminum, and zinc were all found in Flint Run Creek, indicting a release.

The Expanded Site Inspection (ESI) took samples from several locations including the brick dump, acid pond, two carbon disulfide pits, drainage ditches, the Northeast pond, Flint Run Creek, and elsewhere onsite. PCBs (Aroclor 1254) were detected in only one sample (an onsite soil sample by a tank foundation (SS-17), at 490 micrograms per kilogram (490 ppb). An onsite powerhouse was identified as a possible source, the PCB concentration was below residential risk based concentrations (RBCs). Based on a site map, SS-17 appears to be 2000' from Flint Run and 800' from the drainage ditch. There were no PCBs detected in Flint Run Creek. Metals found onsite and in the stream were the contaminants of concern for the site. The site was NFRAPed after the ESI, however, an administrative order was entered into in 1999.

B.2.3. Warren County Landfill

The Warren County landfill is located approximately 2 miles east of Bentonville, Virginia. The landfill is located along Route 613. Drainage from the site goes to two unnamed streams which drain to Flint Run Creek which drains into the Shenandoah River. The 85-acre landfill was still active at the time of the Site Inspection (SI) in 1987, it was expected to close in 1990.

At the time of the SI, a 15-acre portion was still receiving wastes from 4 county dumpsters, Avtex Fibers, and a sewage treatment facility. Avtex at one time disposed of viscose at the facility, but this was discontinued.

During the SI, samples were taken from four home wells, an onsite well, two springs, leachate, an unnamed stream, and various locations on site. There were no PCBs detected in any of the samples, although there were low levels of ketones, phenol, substituted benzenes, and phthalate. This was the last action that occurred, and the site is listed as a low priority.

There is another Warren County Landfill located on Catlet Mountain Road in Front Royal, Virginia. Based on the unvalidated sampling data, this site may be a source of PCBs to the

Shenandoah River. This information has been furnished to EPA's Hazardous Site Cleanup Division, the Town of Front Royal, and Warren County.

B.2.4. Racon Dump Site

In August of 1992, four containers labeled "Racon-11" (trade name for trichlorofluoromethane) were found dumped along State Route 660 in Clarke County, Virginia. On May 3, 1993 the Commonwealth of Virginia contacted EPA about the situation and requested federal assistance to properly sample, transport, and dispose of the four drums. One composite sample was sent out for analysis, and it indicated the drums contained a high level (88.8%) of trichlorofluormethane. On November 15, 1993, the drums were transported to the manufacturer in Wichita, KS. No site assessment actions have taken place.

B.2.5. Aspen Hills Quarry

The Aspen Hills Quarry is located on State Route 643, in Front Royal, Warren County, Virginia and occupies a 65-acre tract of land. An integrated assessment was initiated by a citizen's report that alleged dumping on the property. The complaint alleged that materials from the Avtex site, that were suspected of being hazardous or containing PCBs, were dumped in and on the quarry area.

A multimedia sampling event was conducted on October 29, 1997. A total of 5 soil, 3 water, and 3 sediment samples were collected and analyzed for volatile organics, semivolatile organics, pesticides and PCBs, and metals. All of the samples were collected from areas of suspected contamination with the goal of confirming the presence of hazardous substances. Iron was the only contaminant detected above risk-based concentrations. There were no PCBs detected, and the site was NFRAPed.

B.2.6. Allied Corporation

Allied Corporation is located in Front Royal, Warren County, Virginia. Around 1944, Allied Corporation bought the land from a farmer and began sulfuric acid production. The site had two onsite landfills where process wastes were stored, an onsite containment pond (used to adjust the pH and temperature of non-contact cooling waters), an intermittent stream which discharged the water in the containment pond to the Shenandoah River (this was a permitted discharge), two additional inactive holding ponds, and a compressor which was manufactured in 1944 (which was used to unload sulfuric acid from rail cars).

As part of the 1988 Site Inspection, a total of seven samples were taken from the drainage ditch, onsite ponds, and the intermittent stream. There were elevated concentrations of several organic and inorganic compounds. PCBs (Aroclor 1254) were detected in two samples, one from the intermittent stream that discharges to the South Fork of the Shenandoah and the other in the containment pond, at 3.1 and 4.3 mg/L, respectively. The 1988 report states that "a concentration of 0.79 ng/L in water could result in a PCB concentration in fish tissue that would pose a one-in-one-million cancer risk if consumed regularly. This concentration could easily be exceeded in water draining form the site given the sediment concentrations."

B.2.7. Page County Landfil

The 25-acre Page County landfill is located on Eldon Yates Drive in Stanley, Page County, Virginia. The landfill began operating in 1973 and was still active at the time of the Site Inspection in 1988. At the time of the SI, the manager stated that the facility had never received hazardous or industrial wastes, accepting only municipal wastes. At the time of the 1988 SI ,the facility consisted of a closed cell (vegetated mound), an active cell that was covered with 2 feet of clay daily (a separate mound), and an open pit. None of the cells are lined.

Stoney Run is located adjacent to the site approximately 0.25 miles from the western border. This stream meets the South Fork of the Shenandoah approximately 4 miles northwest of the site. There were no samples taken for either the Preliminary Assessment or Site Inspection. If the site has only received municipal waste, the risk of PCB contamination is small. This site is assumed to not contain PCBs.

B.2.8. Virginia Oak Tannery

Virginia Oak Tannery is located on Route 340 in Luray, Page County, Virginia. Virginia Oak Tannery produces finished leather for shoes and other leather goods. It historically was involved in vegetable and mineral tanning of hides, which resulted in waste streams high in BOD, TSS, and chromium. The facility also used Direct Black 38, a dye which contains benzidine. The discharge from the facility's waste treatment plant degraded the water quality of the receiving stream, Hawksbill Creek, causing two separate fish kills (8/70, 8/76) . Hawksbill Creek is a tributary to the Shenandoah.

In 1980, a new owner took over the facility and the resulting waste streams were eliminated. Sludges from the process lagoons were de-watered and buried in an on-site landfill. The facility shut down all tanning operations in 1980 and connected to the POTW. The site was NFRAPed after an SI in 1982 Samples were taken from Hawksbill Creek as part of the SI. Based on a review of site files it appears as though only aqueous samples were analyzed. There were no PCBs detected as part of the sampling, although no sediment samples were taken. There were elevated levels of Tetrachloroethylene (PCE) (in an onsite well) and some inorganics.

B.2.9. Chemstone Corporation

Chemstone Corporation is located on Route 638 in Strassburg, Shenandoah County, Virginia. Chemstone operates a limestone quarry near Oranda in Northern Shenandoah County, Virginia. A small tributary flows into Cedar Creek, which flows into the North Fork of the Shenandoah. The facility operations began in the early 1900s.There is a disposal area in the northern section of the site for spillage and bag house dust. The site was NFRAPed after a Preliminary Assessment (PA) in 1987.

B.2.10 Genie Corporation

Genie Corporation is located at 611 Williams Avenue, Shenandoah, Page County, Virginia. The EPA WPD requested files for the site. According to Envirofacts, Trichlorethylene (TCE) in the town water supply is suspected to originate from this site. Currently, no more information is available for this site.

B.2.11. Foster Laboratory

Foster Laboratory is located at 684 Kildar Drive, Shenandoah, Virginia. No information is available for this site , EPA WPD is attempting to contact the On-Scene Coordinator.

Appendix C - PCS - Industrial Facilities

NPDES	FACILITY NAME	CITY NAME	RECEIVING WATERBODY
WV0005517	REPUBLIC PAPERBOARD COMPANY OF WV	HALLTOWN	
WV0022349	CHARLES TOWN, CITY OF	CHARLES TOWN	EVITTS RUN
WV0039136	Harpers Ferry-Bolivar PSD	HARPERS FERRY	SHENANDOAH RIVER
WV0088757	CHARLES TOWN RACES, INC.	CHARLES TOWN	FLOWING SPRINGS RUN
WV0103691	DIXIE D. KILHAM HARPERS FERRY CAVERNS MHP		
WV0105155	ALEX RAHMI UNIWEST STP	CHARLES TOWN	POTOMAC/SHENANDOAH
WV0087858	JEFFERSON CO. BD. OF EDUCATION		
WV0100757	JEFFERSON CO. BD. OF EDUCATIONBlue Ridge Elementary		
WV0104370	SYLVAN DEV. LTD., LIAB.CO. LOCUST HILL STP	CHARLES TOWN	EVITTS RUN
WV0085677	SANITARY ASSOCIATES, INC. SHENDO, INC.	CHARLES TOWN	SHENANDOAH RIVER
WV0086452	Willow Springs PSC	CHARLES TOWN	CATTAIL RUN
WV0088013	TUSCAWILLA UTILITIES TUSCAWILLA UTILITIES SUBD.	CHARLES TOWN	EVITTS RUN
VA0002160	E. I. DUPONT DE NEMOURS&CO-WAY	WAYNESBORO	SOUTH RVR
VA0023400	COLD SPRINGS CORRECTIONAL CENTG, COMM OF	GREENVILLE	SOUTH RIVER
VA0024732	MASSANUTTEN PUBLIC SERVICE STPY	HARRISONBURG	QUAIL RUN TO SOUTH FORK SHENANDOAH
VA0058726	HOWELL METAL COMPANY	NEW MARKET	NORTH FORK SHENANDOAH RIVER
VA0066877	AGUSTA COUNTY SVC AUTH-STUARTS	STAUNTON	SOUTH RIVER
VA0071846	ENDLESS CAVERNS	NEW MARKET	SMITH CREEK
VA0073644	VALLEY SANITATION, INC.	TOMS BROOK	NORTH FORK SHENANDOAH RIVER

NPDES	FACILITY NAME	CITY NAME	RECEIVING WATERBODY
VA0086100	BIERER FARM STP	FAIRFAX	CROOKED RUN
VA0087076	SHENANDOAH RETREAT STP	BERRYVILLE	SHENANDOAH RIVER
VA0089346	KAYHILL ESTATES STP	NEW MARKET	NORTH FORK SHENANDOAH RIVER
VA0089362	GREENVILLE STP	GREENVILLE	CHRISTIANS CREEK
VA0089419	WHITE WAY RESTAURANT STP	CHURCHVILLE	JENNINGS BRANCH
VA0089435	CUB RUN TROUT FARM	SHENANDOAH	CUB RUN
VA0073245	COORS SHENANDOAH BREWERY	ELKTON	S. FORK OF SHENANDOAH RIVER/GAP RUN
VA0072907	FLEMING TED M. PRIV. RES.	WOODSTOCK	NORTH FORK SHENANDOAH RIVER
VA0077640	CHARLES W. SURFACE	STAUNTON	DEFINED BRANCH TO LEWIS CREEK
VA0073997	COLLEEN L. SPIVEY	NEW MARKET	NORTH FORK OF SHENANDOAH RIVER
VA0074667	DONALD E. MORRIS	SPRINGFIELD	NORTH FORK SHEN. RIVER
VA0072966	DONALD J. PLUM	MAURERTOWN	NORTH FORK SHENANDOAH RIVER
VA0077194	DORIS E. DELINSKI	SHENANDOAH	PASSAGE CREEK
VA0075825	LINEWEAVER JERRY R. PRIV. RES.	EDINBURG	SHENANDOAH RIVER
VA0072923	FRANCIS THOMAS	MAURERTOWN	NORTH FORK SHENANDOAH RIVER
VA0078182	GARY A SHIPE	STRASBURG	SOUTH FORK TUMBLING RUN
VA0078310	GREGORY A MCCAULEY	STEPHENS CITY	UNN TRIBUTARY OF SHEEPS RUN
VA0075582	STRICKLER TERRY & BARBARA P.R.	STAUNTON	WET-WEATHER STREAM/SMITH CREEK
VA0074756	JAMES HONG	MIDDLETOWN	DRY RUN
VA0075671	JAMES J. GONG	MIDDLETOWN	WEST RUNN
VA0077135	JOE FLEMING	MAURERTOWN	PUGH'D RUN
VA0073351	CHARLES/MAIER PRIV. RES. STP	MAURERTOWN	NORTH FORK SHENANDOAH RIVER
VA0073369	CHARLES/MAIER PRIV. RES. STP	MAURERTOWN	NORTH FORK SHENANDOAH RIVER

Appendix C - PCS - Industrial Facilities

NPDES	FACILITY NAME	CITY NAME	RECEIVING WATERBODY
VA0078271	KIM SMITH	TOMS BROOK	NORTH FORK SHENANDOAH RIVER
VA0074918	LAWRENCE CRISMAN	SHENANDOAH	PASSAGE CREEK
VA0075205	DELLINGER/PARSONS PRIV. RES. S	SHENANDOAH	PASSAGE CREEK
VA0078255	PAT MULLIGAN	STEPHENS CITY	DRAINAGE WAY TO POND
VA0077097	MOYA ALEJANDRO PRIV. RES. STP	WOODSTOCK	NORTH FORK SHENANDOAH RIVER
VA0077101	DELLINGER ROBIN VONDELL PRIV.	WOODSTOCK	NORTH FORK SHENANDOAH RIVER
VA0077143	TERRY O. TAYLOR	PORT REPUBLIC	TRIB TO DUCK RUN
VA0078379	WILLIAM FLOGAUS	SHENANDOAH	UNN TRIB TO S. FORK SHENANDOAH RIVE
VA0075817	WILLIAM J. FULCHER	SHENANDOAH	
VA0077038	GREEN HERBERT PRIV. RES. STP	NEW MARKET	NORTH FORK SHENANDOAH RIVER
VA0075591	SEYMOUR J. MARK PRIV. RES. S	NEW MARKET	WET-WEATHER STREAM/SMITH CREEK
VA0074187	TIBBETTS RICHARD G. PRIV. RES.	BASYE	
VA0078107	DAN WEIR	BENTONVILLE	UNN TRIBUTARY OF SHENANDOAH RIVER
VA0075400	TAYLOR M. SMITH	BRIDGEWATER	THORNY BR. THEN TO NORTH RIVER
VA0077631	CARL C. LEE	BROADWAY	POSITIVE V-DITCH TOWARD WAR BRANCH
VA0074659	CARL ALLMAN	DAYTON	BRIERY BRANCH
VA0074748	LAM GINA V. PRIV. RES. STP	ROCKINGHAM COUNTY	
VA0075264	LAM GINA V. PRIV. RES. STP	DAYTON	DRY RIVER
VA0075281	LAM GINA V. PRIV. RES. STP	DAYTON	DRY RIVER
VA0075183	SKYLINE RESORT INC.	FRONT ROYAL	S. FORK/SHENANDOAH RIVER
VA0077941	BERNICE A BOWERS	DAYTON	UNN TRIBUTARY TO BRIERY CREEK
VA0073041	BETTY D. LAMBERT	EDINBURG	STONEY CREEK NORTH FORK SHENANDOAH
VA0073482	WELCH RALPH R. SR. & C. REILEY PR	EDINBURG	POND ON APPLICANT'S PROPERTY

NPDES	FACILITY NAME	CITY NAME	RECEIVING WATERBODY
VA0073491	WELCH RALPH R. SR. & C. REILEY PR	EDINBURG	POND ON APPLICANT'S PROPERTY
VA0075639	JOHN R. BRENEMAN	EDINBURG	SHEN RIVER (NORTH FOLK)
VA0076163	CREGER ROBERT L. PRIV. RES.	EDINBURG	FALLS RUN
VA0076911	SULLIVAN NANCY PRIV. RES. STP	EDINBURG	N/A
VA0078280	WILLIAM CHARLES HAMILTON	EDINBURG	FARM POND
VA0078638	MARY LOUISE MEADOWS	ELKTON	UNN TRIBUTARY TO BOONE RUN
VA0075752	LIBERTY BAPTIST CHURCH_STP	FREDERICK COUNTY	CROOKED RUN
VA0077186	DANIEL SETTLE	FREDERICK COUNTY	TRIBUTARY OF WRIGHT'S RUN
VA0076929	HARRY R. HILL	FRONT ROYAL	DRY RUN
VA0077950	GRANVILLE J PEARSON	FRONT ROYAL	CEBIN RUN
VA0078069	RUGGLES DANIEL AND NANCY PRIV	FRONT ROYAL	SHENANDOAH RIVER
VA0078247	RICHARD A FURR	FRONT ROYAL	SHENANDOAH RIVER
VA0078352	JAMES O DONAHUE	FRONT ROYAL	NORTH FORK SHENANDAH RIVER
VA0078671	REGINALD AND CAROLYN MAJORS	FRONT ROYAL	UNN TRIB PASSAGE CR N FORK SHENAN
VA0072931	MCGAHEYSVILLE WTP	HARRISONBURG & ROCKI	SOUTH FORK- SHENANDOAH RIVER
VA0073164	HAZEL K. BROWN	LURAY	PASS RUN
VA0078743	KENNETH M LOWE	LURAY	SHENANDOAH RIVER
VA0072770	STEPHEN N. LIVESAY	MAURERTOWN	PUGH'S RUN
VA0075965	CHARLES S. PARNELL	MAURERTOWN	
VA0078689	FRANK D SHAW	MAURERTOWN	NON DISCHARGING FARM POND
VA0072958	HARRY A. DOWNARD	MIDDLETOWN	MOLLY BOOTH RUN
VA0075621	THOMAS THACKER	MOUNT CRAWFORD	NORTH RIVER/UNNAMED CREEK
VA0077992	MARK K. & GLENDA C. BUSTER PRI	MOUNT CRAWFORD	NORTH RIVER

Appendix C - PCS - Industrial Facilities

NPDES	FACILITY NAME	CITY NAME	RECEIVING WATERBODY
VA0072915	NANCY L. SHEPPARD	MOUNT JACKSON	NORTH FORK SHENANDOAH RIVER
VA0075647	PEGGY S. MANDALA	MOUNT JACKSON	RILES RUN
VA0075655	DAVID A. RIHA	MOUNT JACKSON	MILL CREEK
VA0074675	TERRY TAYLOR	ROCKINGHAM COUNTY	CHEESE CREEK
VA0072796	CAMELOT GROCERY & DELI STP	SHENANDOAH	PASSAGE CREEK
VA0074608	FRITZMAN DEWEY & EVA PRIV. RE	SHENANDOAH	N/A
VA0074853	A. J. GOLDENTHAL	SHENANDOAH	PETERS MILL RUN
VA0075663	GROGER JAMES & WANDA PRIV. RES.	SHENANDOAH	PASSAGE CREEK
VA0075728	NANCY PRYOR	SHENANDOAH	PASSAGE CREEK
VA0076082	CELLUCCI THOMAS & SANDRA PRI	SHENANDOAH	FARM POND/PERER'S MILL RUN
VA0078751	ERVIN F CAMPBELL	STANLEY	HONEY RUN
VA0075353	KENNETH R. HYLTON	STEPHENS CITY	SHEEP RUN
VA0075493	E. SUSAN SANDY	STEPHENS CITY	SHEEP'S RUN
VA0075931	ELMO RAY NEFF	STEPHENS CITY	STEPHENS RUN
VA0077160	ARTHUR B. RITENOUR	STEPHENS CITY	AN UNNAMED TRIUTARY OF STEPHENS RUN
VA0073181	ROBERT A. NEFF	STRASBURG	SOUTH FORK TUMBLIN RUN
VA0075051	BURROWS MARLIN & JOYCE PRIV.	STRASBURG	CEDAR CREEK
VA0078298	THOMAS CONRAD	STRASBURG	UNN TRIBUTARY TO CEDAR CREEK
VA0072974	JOHN F. RENO	TOMS BROOK	NORTH FORK SHENANDOAH RIVER
VA0073521	PATRICIA M . MONK	WARREN COUNTY	MELLY BOOTH RUN
VA0074080	LEON E. JENKINS	WARREN COUNTY	GOONEY RUN
VA0074951	MONOFILAMENTS INC	WAYNESBORO	SOUTH RIVER
VA0075949	GLEN A. SMITH	WHITE POST	CROOKED RUN
VA0073547	FRANCIS C. ARTZ	WOODSTOCK	NORTH FORK SHENANDOAH RIVER

NPDES	FACILITY NAME	CITY NAME	RECEIVING WATERBODY
VA0075418	RALPH COFFMAN	WOODSTOCK	NARROW PASSAGE CREEK
VA0078361	MICHAEL T CODY	WOODSTOCK	NARROW PASSAGE CREEK
VA0078514	C THOMAS SOLLENBERGER	WOODSTOCK	UNN TRIB OF NARROWS PASSAGE CREEK
VA0078611	ALLEN R. HOLLAR	WOODSTOCK	FARM POND
VA0075892	ROBERT C. MARSETT PRIV. RES.		
VA0075680	HOWARD H. YOUNG RESIDENCE STP		
VA0075868	A. OWEN SHIFFLETT PRIV. RES.		
VA0001791	ROCCO QUALITY FODDS, INC.	TIMBERVILLE	N FORK SHNDOAH
VA0089061	WOODLAWN VILLAGE M.H. PARK	WAYNESBORO	MEADOW RUN
VA0089095	PIONEER TRAILER PARK	STEPHENS CITY	CROOKED RUN
VA0088994	HARRISONBURG-NEW MARKET KOA	BROADWAY	WAR BRANCH
VA0083305	CAMP OVERLOOK STP	KEEZLETOWN	MOUNTAIN RUN
VA0086738	SOUTH STATES CO-OP., INC., AUGUSTA	STAUNTON	CHRISTIANS CREEK
VA0025151	WAYNESBORO DEPT OF UTILITIES-STP	WAYNESBORO	SOUTH RV SECTION 3 SHENANDOAH RV
VA0025291	AUGUSTA CTY.SER.AUTH-FISHERSVILLE REGL.STP	STAUNTON	CHRISTIANS CREEK
VA0062812	FRONT ROYAL, TOWN OF,STP	FRONT ROYAL	SHENANDOAH RIVER
VA0001864	AILEEN INC,	EDINBURG	N FORK SHNDOA R
VA0002402	GENICOM CORP.	WAYNESBORO	SOUTH RIVER
VA0073474	VIRGINIA METALCRAFTERS INC.	WAYNESBORO	ROCKFISH RUN
VA0001767	REYNOLDS METALS CO.-GROTTOES	AUGUSTA COUNTY	SOUTH RIVER
VA0002313	WAMPLER FOODS-HINTON	ROCKINGHAM COUNTY	WAR BRANCH
VA0001961	WAMPLER-LONGACRE-ALMA	PAGE COUNTY	S FORK SHNDOAH

Appendix C - PCS - Industrial Facilities

NPDES	FACILITY NAME	CITY NAME	RECEIVING WATERBODY
VA0002011	ROCKINGHAM POULTRY, BROADWAY	TIMBERVILLE	N FORK SHNDOAH
VA0060640	HARRISONBURG-ROCKINGHAM SEWER AUTH	ROCKINGHAM COUNTY	NORTH RIVER
VA0064793	CITY OF STAUNTON WWTP	STAUNTON	MIDDLE RIVER
VA0052621	MEADOWGOLD DAIRY PRODUCTS, INC	STRASBURG	SHENANDOAH RIVER
VA0002178	MERCK & CO INC STONEWALL PLANT	ELKTON	S FORK SHNDOAH

Appendix D: Quality Assurance Project Plan (QAPP)

Due to the voluminous nature of the Quality Assurance Project Plan (QAPP), a copy has not been attached to this document. If you would like a copy of this document, please contact EPA Region III's Office of Watersheds program at 215-814-2310.

Appendix E: Shenandoah Sampling Event Photographs

Figure E-1: Shenandoah River, Sieving for Clams

Figure E-2: Dog Run, Collecting Water Samples

Figure E-4: Dog Run, Sieving Clams

Figure E-5: Dog Run, Grab Sediment Sampling

Figure E-6: Shenandoah River, by Millville Dam, WV

Appendix F - Plug Flow Reactor Model

F-1: Water Balance for critical condition

Because of the direct discharges of PCBs are continuous, a long-term balance and a harmonic flow condition, was represented as follows:

$$(Q) = Q_{PCB} + Q_{NPS} + Q_{PS} \tag{F-1a}$$

where Q_{NPS} = flow due to any non point sources [L^3/T]
Q_{PS} = flow due to any point sources [L^3/T]
Q_{PCB} = flow due to PCB discharge [L^3/T]

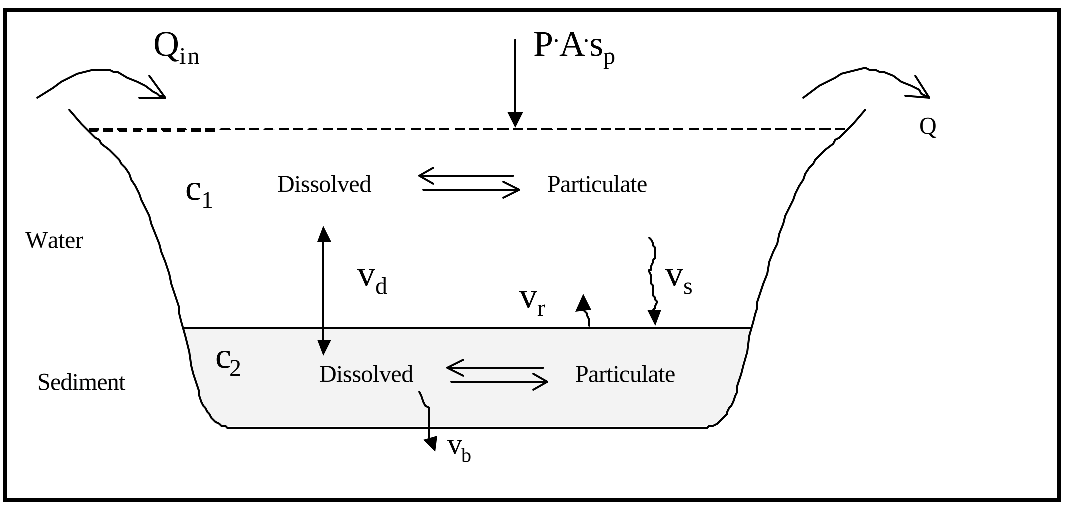

Figure F-1: Processes and Interactions Represented in the Plug-Flow Reactor Model

A mass balance of PCBs can be developed assuming that the PCBs partition into the dissolved and particulate forms and considering the various interactions between the sediment layer and the water column (Figure F-1). (Note: subscript 1 refers to the water column and subscript 2 refers to the sediment layer).

A steady-state budget can be written for a plug-flow system with constant hydro-geometric characteristics as (Chapra, 1997):

$$0 = -U\frac{dm_1}{dx} - \frac{v_s}{H_1}m_1 + \frac{v_r}{H_1}m_2 \qquad \text{(F-1)}$$

$$0 = v_s m_1 - v_r m_2 - v_b m_2 \qquad \text{(F-2)}$$

where: U = stream velocity [L/T]
v_s = settling velocity [L/T]
v_d = sediment-water diffusion rate [L/T]
v_b = burial velocity [L/T]
v_r = resuspension velocity [L/T]
m_1 and m_2 = suspended solids in the water (1) and sediment layers (2) [M/L^3]
s_p = atmospheric deposition rates [M/T]
A_s = surface area [L^2]
H_1 and H_2 = depth of water column (1) and sediment layer (2) [L]

Equation (F-1) refers to the interaction between the water column and sediment layer with respect to the water column and equation (F-2) refers to the interaction between the sediment layer and the water column with respect to the sediment layer.

$$v_r = v_s \frac{m_1}{(1-f)r} \qquad \text{(F-3)}$$

where: f = porosity
= density [M/L^3]
m_{in} = suspended solids concentration coming into the system [M/L^3]

F-2: Contaminant Budget

Assuming a steady state, the contaminant budget can be written for a plug-flow system with constant hydro-geometric characteristics as (Chapra, 1997):

$$0 = -U\frac{dc_1}{dx} = k_1C_1 - \frac{v_v}{H_1}F_{d1}C_1 - \frac{v_s}{H_1}F_{p1}C_1 + \frac{v_d}{H_d}(F_{d2}C_2 - F_{d2}C_2) + \frac{v_r}{H_1}C_2 \qquad \text{(F-4)}$$

and for the bottom sediment as:

$$0 = v_sF_{p1}C_1 + v_d(F_{d1}C_1 - F_{d2}C_2) - k_2H_2C_2 - v_rC_2 - v_bC_2 \qquad \text{(F-5)}$$

where:

- v_s = settling velocity [L/T] (from literature Fox River, WDNR, 2000, suggests a typical value of 0.05-2.5 m/day)
- F_{p1}= fraction of the total PCB that is in water
- F_{d1} = fraction of total PCBs dissolved in water
- F_{d2} = fraction of total PCBs dissolved in sediment
- K_{d1} = PCB partitioning coefficient in water column (L^3/M)
- K_{d2} = PCB partitioning coefficient in sediment layer (L^3/M)
- k_1 and k_2 = first order decomposition rate (1/T)
- v_d = diffusive mixing velocity (L/T)
- M = mean PCB molecular weight

$$F_{p1} = \frac{K_{d1}m_1}{1 + K_{d1}m_1} \qquad \text{(F-6)}$$

$$F_{d1} = \frac{1}{1 + K_{d1}m_1} \qquad \text{(F-7)}$$

$$F_{d2} = \frac{1}{\phi + K_{d2}(1-\phi)\rho} \qquad \text{(F-8)}$$

$$v_d = 69.35 fM^{-2/3} \quad \text{(Di Toro et al., 1981)} \qquad \text{(F-9)}$$

The water column partition coefficient (K_{d1}) for PCBs from literature ranges from 1 x $10^{5.62}$ to $10^{5.93}$ L/kg as reported in the Hudson River, NY 1999 analysis. Thomman and Mueller 1987 report a water column partition coefficient of 1 x 10^5 to 10^6 L/kg and suggest that the sediment partition coefficient (K_{d2}) is usually lower than the water column partition coefficient.

Given a boundary condition of $C_1 = C_1(0)$, and assuming that fraction of particulates are changing with distance, Mills et al. (1985) provide the following solution for the water column concentration:

$$C_1 = C_1(0)e^{\left[\ln\left(K_{d1}m_1 + e^{\frac{v_s x}{H_1 U}}\right) - \ln\left(K_{d1}m_1 + 1\right) - \frac{v_s x}{H_1 U}\right]} \tag{F-10}$$

Because the sediment bed does not advect downstream the concentration of total PCBs in the sediment C_2 can be calculated from equation F-5.

$$C_2 = C_1\left(\frac{v_s F_{p1} + v_d F_{d1}}{(v_r + v_b + k_2 H_2 + v_d F_{d2})}\right) \tag{F-11}$$

where k is a first order decompostion rate (1/T) (assumed to be zero) and H_2 is the depth of the sediment layer. Equation F-11 establishes a direct relationship between the sediment and the overlying water column concentration.

Total PCBs concentration in terms of mass-specific sediment solids concentration (v_2) in the sediment layer can be represented as:

$$v_2 = C_1\left(\frac{v_s F_{p1} + v_d F_{d1}}{(1 - f)r\,(v_r + v_b + k_2 H_2 + v_d F_{d2})}\right) \tag{F-12}$$

Thus the water concentration follows a simple exponential decay and the sediment traces the identical shape.